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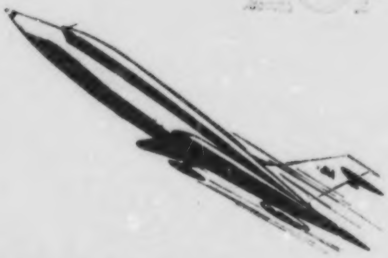

AIRCRAFT EMISSIONS:
IMPACT ON AIR QUALITY
AND FEASIBILITY OF CONTROL

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PREFACE

This report presents the available information on the present and predicted nature and extent of air pollution related to aircraft operations in the United States. In addition, it presents an investigation of the present and future technological feasibility of controlling such emissions. This report is published in accordance with Section 231 (a) of the Clean Air Act as amended, which states:

"(1) Within 90 days after the date of enactment of the Clean Air Amendments of 1970, the Administrator shall commence a study and investigation of emissions of air pollutants from aircraft in order to determine-

"A. the extent to which such emissions affect air quality in air quality control regions throughout the United States, and

"B. the technological feasibility of controlling such emissions

"(2) Within 180 days after commencing such study and investimation, the Administrator shall publish a report of such study and investigation . . ."

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INTRODUCTION

Public awareness that aircraft were a source of air pollution developed in the late 1950's with the introduction of turbine-engine aircraft. Visible exhaust plumes from the engines and increased levels of exhaust odors at airports caused complaints to be lodged. The complaints, in turn, stimulated investigations into the nature and extent of aircraft emissions. The Air Quality Act of 1967 specifically identified aircraft emissions as a subject of concern and required an investigation by the Department of Health, Education, and Welfare. The study[1], submitted to Congress on January 17, 1969, concluded that:

"1. Reduction of particulate emissions from jet aircraft is both desirable and feasible. Engine manufacturers and airlines have indicated that improvements in turbine engine combustor design can be built into new engines and retrofitted on engines already in use. Testing programs are already underway. Furthermore, they have indicated that application of this technology will be underway by the early 1970's. While there are no laws or regulations to compel the industry to follow through on this work, it appears that public pressures resulting primarily from the adverse effects of odors and visibility obscuration will lead industry to initiate the application of this technology as soon as possible and to complete it within the shortest possible time. Accordingly, it is the intention of this Department to encourage such action by engine manufacturers and airline operators and to keep close watch on their progress. If, at any time, it appears that progress is inadequate or that completion of the work will be unduly prolonged, or that the concern of the industry lags, the Department will recommend regulatory action to the Congress that statutory authority for such action be provided.

"2. Further research is needed to define more precisely the present and probable future nature and magnitude of all other air pollution problems associated with aircraft activity in the United States and to identify needs for control measures. Emphasis must be placed particularly on assessment of air pollutant levels in the air terminal environment and their effects on health and safety and on evaluation of possible long-term effects of upper atmospheric pollution resulting from aircraft flight activity. The Department will undertake research appropriate to the solution of this problem.

"3. As further research results in identification of needs for additional measures to control air pollution from any type of aircraft, and as measures to achieve such control become available through research and development, it is the Department's expectation that engine manufacturers, airline operators, and other segments of the aviation community will take the initiative in the development and application of such control measures. If the private sector fails to provide adequate controls, the Department will not hesitate to recommend to the Congress that Federal regulatory action be authorized.

"4. In light of the relatively small contribution of aircraft to community air pollution in all places for which adequate data are available, and in view of the practical problems that would result from State and local regulatory action in this field, it is the Department's conclusion that adoption and enforcement of State or local emission control regulations pertaining to aircraft cannot be adequately justified at this time. The Department recommends that, if and when regulations become necessary, the rationale used to develop Federal rather than local emission standards for motor vehicles be applied to aircraft.

"5. The Department recognizes that State and local agencies, in cooperation with the Federal Aviation Administration and other cognizant agencies, are the most appropriate groups to insure that control of airport pollution hazards will be given adequate consideration in the selection of airport sites, planning for expansion and reconstruction of airports, design of airports, and planning and conduct of ground operations.

"6. The Department will include information on progress in the control of air pollution from aircraft in the annual report which must be submitted under section 306 of the Air Quality Act."

As a result of conclusion (1) above, in March 1970, at a meeting held by the Secretaries of Health, Education, and Welfare and of Transportation, representatives of 31 airlines agreed to a schedule for retrofitting JT8D engines with reduced smoke combustors, to be substantially completed by the end of 1972. This agreement sought to significantly ate visible (smoke) emissions from aircraft powered by this widely used engine. This retrofit program is 85% complete (July 1972). Conclusion (2) pointed to the need for studying air terminal environments, a need which led to an EPA-sponsored study of Los Angeles International Airport by the Los Angeles Air Pollution Control District. This study was completed in April 1971.[2]

Passage of the 1970 Clean Air Act Amendments essentially required that we reassess the aircraft emissions problem and update our knowledge concerning the air quality impact and feasibility of control of such emissions.

The data base for this report includes information developed by Northern Research and Engineering[3] [4], Cornell Research Laboratories[5], the previously cited LAPCD study, and information compiled separately by EPA personnel.

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CONCLUSIONS

The various approaches taken in this study to assess the impact of aircraft on air quality indicate, both individually and collectively, that aircraft operations "cause or contribute to or are likely to cause or contribute to air pollution which endangers the public health or welfare" (Sec. 231(a), Clean Air Act Amendments of 1970). Based on this general conclusion a realistic program of emissions control should be instituted. Though such a control program cannot be quantitatively related to the air quality considerations discussed herein, pollutant emissions from aircraft and aircraft engines should be reduced through the application of the present and prospective technology described in this study. A control program should have inherent flexibility so that as more extensive impact data become available the required controls can be modified accordingly.

The results of EPA's current study of aircraft emissions and their control have led to the following specific conclusions:

1. Aircraft emissions are significant contributors to the regional burden of pollution in comparison to other sources which will have to be controlled to meet National Ambient Air Quality Standards.

2. When airports are viewed as concentrated area sources of pollution emissions, either in isolation or in concert with their surrounding pollution sources, it can be demonstrated that airports will probably exert localized impact on air quality, in excess of the standards, even though relief is provided elsewhere in the region by controls relating to automobiles and stationary sources. That is, unless aircraft emissions are reduced, airports will still remain intense area emitters of pollutants when the emission densities in the surrounding region have been greatly reduced.

3. Aircraft emissions have impact on air quality in residential and business areas adjacent to major U. S. airports. The control of non-aircraft sources in and around such airports will not be adequate to insure compliance with the National Ambient Air Quality Standards indicating the need for controlling aircraft emissions.

4. There exists a variety of control techniques for effecting aircraft emissions reductions which appear both feasible and economically attractive during the next two decades. Emissions may be reduced by means of the following general approaches:

3

(a) Modification of ground operational procedures.

(b) Improvement in maintenance and quality control procedures to minimize emissions from existing families of turbine engines.

(c) Development and demonstration of new combustion technology for major reductions in emissions from second-generation turbine and piston aircraft engines.

(d) Retrofit of turbine engine fleets with existing technology for near-term reduction of emissions.

METHODOLOGY FOR IMPACT ASSESSMENT

Assessment of air quality impact involves investigation at several different levels: (a) global, (b) regional (sub-global), (c) urban, and (d) local. In this report the urban level is defined as an air quality control region. The ability to conduct investigations or assessment at these levels depends entirely on the analytical tools and data bases available. Until quite recently most assessments were source oriented and presented data in terms of national or air quality control region inventories. With the development of models and more refined monitoring systems, we can now explore the more localized "hot spots" within an urban area. The earlier report[1] on the impact of aircraft emissions dealt only with national and regional inventories and projections of aircraft emissions and pointed to the need for a closer look at local airports and their immediate environments. Hence, this study concentrates on assessing local effects through a combination of approaches involving monitoring, statistical analysis, and modeling. Additionally, aircraft emissions are compared with those from other sources of the same pollutants in terms of relative importance and relative cost of control.

The potential impact of aircraft emissions on the global and sub-global environments is not being ignored. Studies of pollution at these levels involve an integrated assessment of all contributors to the global pollution inventory, and hence are beyond the scope of this report. The Clean Air Act mandates that EPA study the geophysical effects of air pollution. Research and monitoring components of EPA are now engaged in preliminary phases of such studies.

To provide continuity, we have updated pertinent data prepared by Northern Research and Engineering which was contained in the previous report[1]. Discrepancies between similar data presentations in the two reports result from the better data base obtained in this study.

NATIONAL AMBIENT AIR QUALITY STANDARDS

In order to assess the significance of aircraft emissions, one must evaluate their contribution to pollutant concentrations in the atmosphere and relate the resulting concentrations to the national ambient air quality standards.

In accordance with the Clean Air Act Amendments of 1970, the EPA established primary and secondary ambient air quality standards[6] for six major pollutants: carbon monoxide, nitrogen dioxide, hydrocarbons, photochemical oxidants, sulfur dioxide, and particulates. The primary standards provide for protection of public health and the secondary standards for prevention of all other undesirable effects of air pollution. Table 1 shows the national standards for these six pollutants.

It should be noted that nonmethane hydrocarbons at concentrations observed in the atmosphere have not been associated with health effects. The relationship between nonmethane hydrocarbons and photochemical oxidants indicates, however, that peak photochemical oxidant concentrations are associated with hydrocarbon concentrations averaged over the time period from 6 to 9 a.m.[7] The peak oxidant levels normally appear some three hours later. The nonmethane hydrocarbon standard is based on this relationship.

As a basis for implementation of the standards, the entire United States has been divided into some 240 Air Quality Control Regions[8]. Regional boundaries are based on considerations of urban-industrial concentration, existing jurisdictional boundaries, and other factors including topography and meteorology, which would affect levels of air quality in an area.

In accordance with the provisions of Section 110 of the Clean Air Act, the States have submitted plans that provide for the implementation, maintenance, and enforcement of the national air quality standards on a regional (air quality region) basis. The State implementation plan for each region must provide for attainment of the primary standards in 3-5 years depending on whether an extension has been granted. The State plan is required to set forth the procedure for attaining the secondary standards within a reasonable amount of time.

Strategies which States are proposing to meet the standards and the possible impact aircraft emissions and

Table I NATIONAL AMBIENT AIR QUALITY STANDARDS

Pollutant	Standard Description
Carbon monoxide (Primary and secondary standards are the same)	- 10 milligrams per cubic meter (9 ppm), maximum 8-hour concentration not to be exceeded more than once per year. - 40 milligrams per cubic meter (35 ppm), maximum 1-hour concentration not to be exceeded more than once per year.
Nitrogen dioxide (Primary and secondary standards are the same)	- 100 micrograms per cubic meter (0.05 ppm), annual arithmetic mean.
Hydrocarbons (non-methane) (Primary and secondary standards are the same)	- 160 micrograms per cubic meter (0.24 ppm), maximum 3-hour concentration (6-9 a.m.) not to be exceeded more than once per year. For use as a guide in devising implementation plans to meet the oxidant standards.
Particulate matter	
Primary standard	- 75 micrograms per cubic meter, annual geometric mean. - 260 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year.
Secondary standard	- 60 micrograms per cubic meter, annual geometric mean, as a guide to be used in assessing implementation plans to achieve the 24-hour standard. - 150 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year.
Sulfur dioxide	
Primary standard	- 80 micrograms per cubic meter, annual arithmetic mean. - 365 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year.
Secondary standard	- 60 micrograms per cubic meter, annual arithmetic mean. - 260 micrograms per cubic meter, maximum 24-hour concentration not to be exceeded more than once per year. - 1300 micrograms per cubic meter, maximum 3-hour concentration not to be exceeded more than once per year.
Oxidant (Primary and secondary standards are the same)	- 160 micrograms per cubic meter, maximum 1-hour concentration, not to be exceeded more than once per year.

their control are discussed in the section on regional impact.

BASIC REQUIREMENT FOR IMPACT EVALUATION

EMISSION FACTORS

Pollutants emitted by aircraft engines include gaseous hydrocarbons, carbon monoxide, oxides of nitrogen, particulate matter, and sulfur oxides. In order to evaluate the impact of aircraft emissions on the ambient air levels of these pollutants, the logical first step is an estimate of the total emissions due to aircraft. Because emission rates vary according to engine type, number of engines and operating mode, we have classified aircraft by type, defined the typical operating modes for each class throughout their landing and takeoff (LTO) cycles, and determined emission factors for each class operating in each mode.

The aircraft classification system groups aircraft into 12 separate types that include the currently used commercial air carriers, and general aviation, and military aircraft. (Classes 8-11 are exclusively military aircraft and are excluded from further consideration in this report.) Provision was also made in the classification system for the possible introduction of supersonic commercial aircraft in the future. The basis for classification of civilian and commercial aircraft is presented in Table 2.

The aircraft modes of operation for which emission rates were categorized are:

(1) Start-up and idle.
(2) Taxi
(3) Idle at runway
(4) Takeoff
(5) Climb-out to 3,000 foot elevation
(6) Fuel dumping
(7) Approach from 3,000 foot elevation
(8) Landing
(9) Idle and shutdown
(10) Maintenance

Emission factors were developed for the civil aviation aircraft classes. A representative listing of emission factors for piston and turbine engines is presented in subsequent discussions of control feasibility.

TABLE 2

AIRCRAFT CLASSIFICATION SYSTEM

Category	Class	Ref. 14 classification	Type	Examples	Engine Model	Type	Thrust or power[a]	Engines per aircraft
Air Carrier	1	-	Supersonic transport	Concorde Tupolev TU-144	R-R/Snecma Olympus 593	Turbojet	39,000 lb.	4
	2		Jumbo jet transport	Boeing 747 Douglas DC-10	P&WA JT9D	Turbofan	43,000 lb.	4
	3	1	Long-range jet transport	Boeing 707 Douglas DC-8	P&WA JT3D	Turbofan	18,000 lb.	4
	4	2	Medium range jet transport	Boeing 727 Douglas DC-9	P&WA JT8D	Turbofan	13,900 lb.	2.6
	5	4	Turboprop transport	Lockheed Electra Fairchild Hiller FH-227	Allison 501-D13	Turbo-prop	3,750 hp.	2.5
General Aviation	6	3	Business jet	Lockheed Jetstar North American Sabreliner	P&WA JT12	Turbojet	2,900 lb.	2.1
	7	6	Piston-engine utility	Cessna 210 Centurion Piper 32-300 Cherokee Six	Continental 10-520-A	Opposed piston	292 hp.	1[b]
V/Stol	12	7	Helicopters and V/STOL	Silorsky S-61 Vertol 107	General Electric CT58	Turbo-shaft	1,390 hp.	2

[a] Equivalent shaft power.

[b] Representative of Van Nuys and Tamiami.

The aircraft emission data, obtained through various research programs funded by EPA, are summarized in the report prepared for EPA by Cornell University.[5]

Emissions from non-aircraft sources on and around the airport are also accounted for in the air quality analyses. These sources of emissions include airport heating plants, fuel storage losses, automobiles, service vehicles, and areas neighboring the airports. To estimate the impact of aircraft emissions on air quality near the ground, one must take into account emissions from the time an aircraft enters the atmospheric mixing layer during approach until it leaves this layer during climb-out. In defining an LTO cycle representative of this consideration, a height of 3,000 feet above the runway was selected as a reasonable approximation of atmospheric mixing depth over major U. S. metropolitan areas.[1] The number of LTO cycles performed, and the relative lengths of time spent in each operational mode of an LTO cycle, combined with the appropriate emission factors, determine the quantities of pollutants emitted by aircraft.

SELECTION OF CRITICAL AREAS AND AIRPORTS

Once the general emission characteristics of aircraft were determined, specific regions and airports having high aircraft activity and air pollution potential were selected for impact evaluation.

As a part of the Northern study[3], several airports were selected to represent, as nearly as possible, those at which the impact of emissions from aircraft and related activities would probably be greatest. The factors considered in evaluating the potential impact of individual airports included: (1) aircraft activity levels, (2) airport area, (3) mean wind speed, and (4) relative activity of different types of aircraft (commercial air carrier and general aviation). On the basis of these considerations and the availability of airport and aircraft activity data, these airports were selected for study:

(1) Commercial Air Carrier

Los Angeles International

Washington National

J. F. Kennedy International

O'Hare International

(2) General Aviation

Van Nuys, California

Tamiami, Florida

Less elaborate evaluations of four additional airports and their impact in their respective air quality control regions were developed as the regional impact analysis was expanded to include an examination of State implementation plans for the attainment of the air quality standards.

The four additional airports, located in San Francisco, Dallas-Ft. Worth, Denver, and Boston, were selected on the basis of high levels of aircraft activity and severity of the regional pollutant levels.

EMISSION PROJECTIONS

The basic emission factors for any particular engine type are not expected to change substantially with time unless changes are required by emission standards. In addition, the number and type of engines representative of one particular class of aircraft are not expected to change substantially in the next 10-20 years. The important and determining factors affecting the projected controlled or uncontrolled emissions are: (1) changes in the level of airport activity, and (2) changes in the mix of the various classes of aircraft.

As a part of the Northern Research Study, records of aircraft activity by class were obtained for the selected airports. Prospective growth in activity at each airport was estimated by projecting past and current activity data to 1975 and 1980. The general trend at the selected airports is towards more aircraft operations in classes 1. 2, 4, 6 and 7; and less in classes 3 and 5. The total yearly activity data and projections are summarized in Table 3.

The air carrier airports are so-called because of the preponderance of commercial air carrier activity, which, in 1970, ranged from 66 percent of total activity at Washington National to 92 percent at Chicago O'Hare. Activity at Tamiami and Van Nuys Airports is approximately 99 percent general aviation aircraft.

Additionally, data were obtained on the uses and locations of taxiways, runways, terminals, hangars, heating plants, fuel storage areas, and roadways at each airport in order to

Table 3

Present and Projected LTO Cycles for 1970, 1975, and 1980

Airport	Type of aircraft				Total LTO cycles		
	Air carrier	General aviation	Military	Helicopters	1970[a]	1975	1980
All FAA operated airports	-	-	-	-	28×10^6	39×10^6	59×10^6
Air carrier airports							
Los Angeles International	203,900	59,900	4,200	4,050	272,000	305,200	358,100
Washington National	109,800	55,500	1,500	-	166,700	169,800	173,500
J. F. Kennedy International	188,800	27,800	-	-	219,200	208,500	241,300
Chicago	314,300	21,200	-	-	339,900	357,000	410,800
General aviation airports							
Van Nuys, California	20	279,400	2,700	-	281,600	-	700,000
Tamiami,[b] Florida	-	200,800	-	-	200,800	-	-

[a] Where parts do not add up to total, LTO cycles not classified by type were included in total

[b] 1971 estimated activity

locate and quantify the various sources of emissions during the operation of aircraft.

Based on projections from Reference 3, revised to incorporate more accurate emission factors, total projected emissions of pollutants from aircraft and from all sources were calculated for the years 1975 and 1980 at each of the selected airports except New Tamiami (which lacked reliable activity projections). These projections are presented in Table 4 for total hydrocarbons, carbon monoxide, nitrogen oxides, sulfur dioxide, particulate matter (including lead), and lead. For a more complete assessment of proposed control strategies, emission projections for three of the pollutants (hydrocarbons, carbon monoxide, and nitrogen oxides) were also developed for 1990. The projected values for 1990 are presented in the discussion of control feasibility and impact. The emission projections are based on present emission rates for each aircraft engine class and do not incorporate potential future reductions in emissions as a result of aircraft emission standards. The projected aircraft emissions reflect increased activity and changes in the mix of existing engines.

At the four air carrier airports during the 1970's, as a result of continued introduction of jet engines found in present-day new jet aircraft, total emissions of carbon monoxide from aircraft are not projected to change greatly. Hydrocarbon emissions, however, although predicted to increase by 18 percent at Washington National Airport, are expected to decrease by about 60 to 70 percent at Los Angeles, John F. Kennedy, and O'Hare Airport. The estimated average increase in aircraft operations is 20 percent at these airports during the 1970's, indicating in general, lower hydrocarbon and carbon monoxide emissions from the newer and, in many cases, larger engines. As shown in Table 4 there will be substantial increases in aircraft NOx emissions of 275 percent at Los Angeles, 146 percent at John F. Kennedy, 98 percent at O'Hare, and 33 percent at Washington National Airport between 1970 and 1980. These increases reflect the greater amounts of NOx emitted during an entire LTO cycle from the newer engines. Some increases in SO2 and particulate emissions from aircraft are projected, since such increases usually follow increases in aircraft operations.

At Van Nuys Airport, the projected increases in all pollutants parallel the large projected increases in activity at this airport. During the 1970's, emissions of hydrocarbons, carbon monoxide, NOx, and lead from aircraft are projected to increase by about 140 percent.

As Table 4 indicates, we estimate that in 1975 CO emissions from aircraft at Van Nuys Airport will exceed CO emissions from aircraft at a major commercial airport, Washington National. This estimation indicates the increasing importance of general aviation aircraft emissions, and emphasizes that during an LTO cycle, CO emissions from a small general aviation piston engine can, in many cases, be expected to approach CO emissions from a commercial air carrier turbine engine.

The existing and potential air quality impact of sulfur oxides and lead is considered to be negligible in comparison to other sources of these two pollutants. Therefore, no further analysis was performed on these pollutants in this study. The particulate problem associated with aircraft operations has already been shown to be confined to the smoke problem and hence the air quality impact discussion is very brief in this report.

Emission projections for the additional airports at Dallas-Ft. Worth, San Francisco, Denver, and Boston were based on the similarity of the particular airport to one or more of those in Table 4.

Table 4. CURRENT AND PROJECTED EMISSIONS[a] FROM AIRCRAFT AND AIRPORTS
(tons/year)

Airport and year	Particulates[b]		NO_x		SO_2		Lead		Carbon monoxide		Total hydrocarbons	
	Aircraft	Airport total	Aircraft	Airport total	Aircraft	Airport total	Aircraft	Airport total	Aircraft	Airport total	Aircraft	Airport total
Los Angeles												
1970	570	616	3,060	4,369	431	434	0.3	35.2	16,030	29,230	12,570	14,660
1975	610	627	6,790	8,110	490	561	0.9	22.0	16,630	28,730	8,660	10,530
1980	680	693	11,490	12,480	623	726	1.0	7.8	18,480	27,280	4,770	5,760
Washington National												
1970	231	253	820	1,074	105	319	0.5	4.8	2,410	3,731	610	864
1975	242	253	980	1,211	121	330	0.5	2.1	2,700	3,691	680	823
1980	286	297	1,090	1,277	143	352	0.5	0.9	3,030	3,470	720	775
John F. Kennedy												
1970	570	660	2,580	4,846	418	902	0.3	53.9	12,590	32,390	9,490	12,680
1975	550	605	4,660	6,640	415	913	0.4	27.5	11,280	26,680	5,700	8,010
1980	550	583	6,370	7,580	442	957	0.9	7.8	10,680	18,380	2,830	3,930
O'Hare												
1970	900	1,001	3,760	6,290	562	605	0.2	63.8	14,740	34,540	9,580	13,210
1975	970	1,023	5,760	7,520	600	660	0.4	28.6	13,840	31,440	6,300	8,830
1980	1,100	1,100	7,440	8,540	718	803	0.6	7.7	13,530	22,330	3,710	4,920
Van Nuys												
1970	3.2	3.7	12.1	27.5	0.033	0.33	3.2	3.6	1,650	1,870	100	132
1975	5.4	5.7	19.8	34.1	0.066	0.55	5.3	5.5	2,750	2,860	165	198
1980	7.7	7.8	28.6	36.3	0.099	0.88	7.6	7.6	3,960	4,070	242	264

[a] Based on aircraft emissions below 3000 feet altitude.

[b] Includes lead.

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RESULTS OF IMPACT EVALUATION

REGIONAL IMPACT

The implementation plans of eight air quality control regions were reviewed in detail. These regions have critical problems in terms of their ability to meet the National Ambient Air Quality Standards and also have airports with high air passenger activity. Four of the regions considered are those in which the four major air carrier facilities considered in the Northern Research Study are located. The analysis of regional implementation strategies was extended to include San Francisco, Boston, Denver, and Dallas-Fort Worth. Table 5 reflects the present status of implementation plans relating to the control strategies (by pollutant) for these regions and their ability to meet the air quality standards by 1975.

As an aid in assessing aircraft emissions and their regional impact Tables 6 through 13 present the 1970 emission inventories and emission projections for 1975 and 1980, for the eight regions cited, along with reductions expected as a result of Federal standards for emissions from light-duty motor vehicles.[9] In addition, one or more of the proposed strategies representing control of smaller sources or additional controls on motor vehicle sources are cited so that the spectrum of control demands is evident. Present and projected estimates of aircraft emissions are also tabulated, along with the reductions to be expected if the proposed standards are met. The reductions for 1975 represent application of the only feasible control strategy available by that date, ground operation control. Two values are shown for 1980 potential reduction: the first represents the actual reductions achievable by 1980; the second, mass reductions achievable in the 1980-1990 time frame as a result of the proposed 1979 design standards.

Note that in 9 of the 17 possible region/pollutant combinations (an 8-region by 2-pollutant matrix plus Los Angeles NOx) the potential reductions in aircraft emissions are comparable to (at least half of) or greater than the reductions due to minimum strategies proposed for 1980 by the various regional or State agencies.

TABLE 5

ABILITY TO MEET NATIONAL AMBIENT AIR QUALITY STANDARDS IN 1975

(yes = able, no = unable)

Based on Current State Implementation Plan Information

Region	Pollutant		
	CO	HC	NO_2*
1. Los Angeles	Yes	No	No
2. New York	No	No	--
3. Washington, D.C.	No	Yes	--
4. Chicago	Yes	Yes	--
5. Denver	No	No	--
6. San Francisco	Yes	No	--
7. Dallas/Fort Worth	Yes	Yes	--
8. Boston	No	No	--

*NO_2 air quality data is currently being reevaluated. Results of this reassessment may require additional or accelerated control of aircraft NO_x emissions to those herein proposed.

TABLE 6

METROPOLITAN LOS ANGELES INTRASTATE AQCR
EMISSIONS, KILOTONS PER YEAR

EMISSIONS	1970 CO	1970 HC[a]	1970 NO_x	1975 CO	1975 HC[a]	1975 NO_x	1980[c] CO	1980[c] HC[a]	1980[c] NO_x
WITHOUT ADDITIONAL CONTROLS									
Region	4,130	651	573	4,400	693	611	4,800	756	668
Aircraft (for entire region)	41.1	6.8	4.2	51.4	4.9	9.3	70.0	3.2	15.6
REGION WITH PROPOSED CONTROLS (Aircraft control not included)				880	178	335	515	130	275
REDUCTION FOR SPECIFIC STRATEGIES									
Present motor vehicle program				2,200	365	164	3,720	548	350
Petroleum industry					23.7			25.5	
Organic solvents					1.8			2.2	
Incineration				14.6		1.1	16.4		1.1
Combustion of fuels						9.1			9.1
Agriculture				1.8			2.2		
Periodic vehicle inspection				584	25.6	+16.4[b]	230	7.3	+14.6[b]
Retrofit evaporative control					34.7			9.1	
1/3 conversion to gaseous fuels				485	27.4	73	175	7.3	25.6
20% traffic reduction				200.7	30.8	47.5	109.5	18.3	27.4
AIRCRAFT CONTROL									
Turbine ground operation				10.4	2.5		10.9	1.3	
Turbine emission standard					0.3		1.9 (25.8)	0.4 (2.7)	1.0 (13.4)
Piston emission standard							2.3 (30.9)	0.0 (0.3)	
Sum of aircraft control strategies				10.4	2.8	0	15.1 56.7	1.7 3.0	1.0 13.4

[a] Reactive HC based on California SIP

[b] Increase rather than decrease due to engine operation tradeoff

[c] Values shown in parenthesis are projected 1990 emission reductions.

TABLE 7

NEW YORK PORTION OF THE N.J. - N.Y. - CONN. INTERSTATE AQCR EMISSIONS, KILOTONS PER YEAR

EMISSIONS	1970 CO	1970 HC	1970 NO_x	1975 CO	1975 HC	1975 NO_x	1980[d] CO	1980[d] HC	1980[d] NO_x
WITHOUT ADDITIONAL CONTROLS									
Region	4,207	832	741	4,840	955	851	5,260	1,040	926
Aircraft (JFK only)	12.6	9.5	2.6	11.3	5.7	4.7	10.7	2.8	6.4
WITH STATE PROPOSED CONTROLS									
Region				2,630	485	727	1,136	268	622
REDUCTION FOR SPECIFIC STRATEGIES									
National Motor Vehicle Standards				2,139	431	101	4,066	702	269
(Other Strategies)				41[a]	20.8[b]	23.6[c]	44.6[a]	21[b]	25.6[c]
AIRCRAFT CONTROL									
Ground Operation				5.7	3.6		5.1	1.6	
Emission Standards					.4		0.8 (9.6)	0.6 (3.0)	0.5 (6.1)

Note: La Guardia ≅ 60-70% of JFK.

[a] Downtown truck control.

[b] Process evaporation.

[c] Gas space heat downtown.

[d] Values shown in parenthesis are projected 1990 emission reductions.

TABLE 8

NATIONAL CAPITAL INTERSTATE AQCR
EMISSIONS, KILOTONS PER YEAR

EMISSIONS	1970 CO	1970 HC	1970 NO_x	1975 CO	1975 HC	1975 NO_x	1980[c] CO	1980[c] HC	1980[c] NO_x
WITHOUT ADDITIONAL CONTROLS									
Region	1,389	267	184	1,554	299	206	1,735	335	230
Aircraft (National)	2.4	0.6	0.8	2.7	0.7	0.9	3.0	0.7	1.1
WITH STATE PROPOSED CONTROLS									
Region				1,025	155	188	460	117	150
REDUCTION FOR SPECIFIC STRATEGIES									
National Motor Vehicle Standards				470	97	20	1,215	190	78
Minimum Strategies				25.2[a]	2.2[a]	0.5[b]	11.3[a]	1.3[a]	0.3[b]
AIRCRAFT CONTROL									
Ground Operation				1.1	.3		1.2	.4	
Emission Standards					0.1		0.2 (2.9)	0.2 (0.7)	0.1 (1.0)

[a] Use of liquified petroleum gas for fleet vehicles.
[b] Motor vehicle maintenance and inspection.
[c] Values shown in parenthesis are projected 1990 emission reductions.

TABLE 9

ILLINOIS PORTION OF THE METROPOLITAN CHICAGO INTERSTATE AQCR
EMISSIONS, KILOTONS PER YEAR

EMISSIONS	1970 CO	1970 HC	1970 NO_x	1975 CO	1975 HC	1975 NO_x	1980[e] CO	1980[e] HC	1980[e] NO_x
WITHOUT ADDITIONAL CONTROLS									
Region	2,730	606	383	3,064	688	435	3,496	796	504
Aircraft (O'Hare)	14.7	9.6	3.8	13.8	6.3	5.8	13.3	3.7	7.4
WITH STATE PROPOSED CONTROLS									
Region				1,480	235.5	306	506	96	196
REDUCTION FOR SPECIFIC STRATEGIES									
National Motor Vehicle Standards				1,383	262	94.5	2,748	465	265
Aggregate Stationary Source Controls[a]				4.4[b]	1.1[c]	6.0[d]	5.3[b]	1.3[c]	7.4[d]
AIRCRAFT CONTROL									
Ground Operation				6.5	3.6		6.2	2.0	
Emission Standards					0.6		1.1 12.2	0.8 3.9	0.6 (6.5)

Note: Midway emissions ≅ 20% O'Hare.

[a] Minimum source strategy assumed to be 10% of aggregate.

[b] Incinerators.

[c] Refinery solvents.

[d] Values shown in parenthesis are projected 1990 emission reductions.

TABLE 10

METROPOLITAN DENVER INTRASTATE AQCR
EMISSIONS, KILOTONS PER YEAR

EMISSIONS	1970 CO	1970 HC	1970 NO_x	1975 CO	1975 HC	1975 NO_x	1980[a] CO	1980[a] HC	1980[a] NO_x
WITHOUT ADDITIONAL CONTROLS									
Region	873	174	139	965	192	154	1,065	212	170
Aircraft (Stapleton)	4.5	2.6	1.0	4.6	1.7	1.6	4.8	1.0	2.0
WITH STATE PROPOSED CONTROLS									
Region				516	98		252	65	
REDUCTION FOR SPECIFIC STRATEGIES									
National Motor Vehicle Standards				280	70		757	140	
Retrofit Pre '67 Cars				66	14.5		12	2.6	
Tune-ups				103	9		44	4	
AIRCRAFT CONTROL									
Ground Operation				1.8	1.0		1.7	0.5	
Emission Standards					0.2		0.3 (3.5)	0.2 (1.1)	0.2 (1.8)

[a] Values shown in parenthesis are projected 1990 emission reductions.

TABLE .11

SAN FRANCISCO BAY AREA INTRASTATE AQCR
EMISSIONS, KILOTONS PER YEAR

EMISSIONS	1970 CO	 HC[b]	 NO$_x$	1975 CO	 HC[b]	 NO$_x$	1980[a] CO	 HC[b]	 NO$_x$
WITHOUT ADDITIONAL CONTROLS									
Region	1,980	315	266	2,150	340	287	2,350	371	313
Aircraft (S.F. Int'l.)	11.0	3.2	2.1	11.5	2.2	4.7	12.7	1.2	7.9
WITH STATE PROPOSED CONTROLS									
Region				451	89	156	291	69	125
REDUCTION FOR SPECIFIC STRATEGIES									
National Motor Vehicle Standards				1,030	172	77	1,730	252	164
Minimum Strategies				16[c]	.7[c]	21.8[d]	18[c]	.7[c]	10.8[e]
Vehicle Inspection				266	10.9	+7.3[f]	106	2.9	+7.3[f]
AIRCRAFT CONTROL									
Ground Operation				5.3	1.3		5.6	0.7	
Emission Standards				0	0.1		1.0 13.3	0.2 1.4	0.5 6.8

Note: Oakland and San Jose ≅ 20% of S.F. Int'l.
[a] Values shown in parenthesis are projected 1990 emission reductions.
[b] Defined highly reactive.
[c] Agricultural burning.
[d] 20% traffic reduction.
[e] 1/3 conversion to gaseous fuels.
[f] Increase rather than reduction.

TABLE 12

METROPOLITAN DALLAS - FORT WORTH INTRASTATE AQCR EMISSIONS, KILOTONS PER YEAR

EMISSIONS	1970 CO	1970 HC	1970 NO_x	1975 CO	1975 HC	1975 NO_x	1980[a] CO	1980[a] HC	1980[a] NO_x
WITHOUT ADDITIONAL CONTROLS									
Region	2,340	454	280	2,620	509	314	2,920	567	350
Aircraft (Love Field)	7.2	4.5	1.8	6.9	3.0	2.7	6.7	1.8	3.5
WITH STATE PROPOSED CONTROLS									
Region					256	270		149	178
REDUCTION FOR SPECIFIC STRATEGIES									
National Motor Vehicle Standards					199	44		393	172
Minimum, Control Stationary Source and Gases					6.4			6.4	
Maintenance and Inspection					48			19	
AIRCRAFT CONTROL									
Ground Operation				3.1	1.7		2.9	0.9	
Emission Standards					0.3		0.5 (5.9)	0.4 1.8	0.3 (3.2)

[a] Values shown in parenthesis are projected 1990 emission reductions.

TABLE 13

METROPOLITAN BOSTON INTRASTATE AQCR
EMISSIONS, KILOTONS PER YEAR

EMISSIONS	1970			1975			1980[a]		
	CO	HC	NO_x	CO	HC	NO_x	CO	HC	NO_x
WITHOUT ADDITIONAL CONTROLS									
Region	1,352	263	206	1,555	302	237	1,690	329	258
Aircraft (Logan)	7.9	5.8	1.6	7.0	3.5	2.8	6.5	1.7	3.9
WITH STATE PROPOSED CONTROLS									
Region				1,034	141.5	211.7	490	82	183
REDUCTION FOR SPECIFIC STRATEGIES									
National Motor Vehicle Standards				502	95	25	1,200	178	75
Gasoline Handling Evaporative Losses					12			13	
Solvent Control					52			56	
Other Strategies Sited None Actually Proposed									
AIRCRAFT CONTROL									
Ground Operation				3.5	2.2		3.1	1.0	
Emission Standards					0.2		0.5 (5.9)	0.4 (1.8)	0.3 (3.7)

[a] Values shown in parenthesis are projected 1990 emission reductions.

More importantly, in 4 or these 9 cases, the air quality standard will not be met or will be only marginally met in the 1975-1980 time frame. In these cases aircraft emission reductions before and after 1980 would represent effective control strategies. In all regions facing difficulties in meeting the air quality standards, every viable control strategy will have to be applied to meet requirements of the Clean Air Act.

Table 6, which relates to the implementation plan for metropolitan Los Angeles, lists all proposed strategies and gives aircraft emission figures representative of all aircraft activity, including LAX, in the region. For a specific region, total aircraft emissions can be substantially higher than those attributed to the area's major air carrier airport. The region encompassing metropolitan Los Angeles, for example, includes, besides LAX, several smaller commercial air carrier airports and numerous general aviation facilities. It is not surprising then that LAX accounts for only 40%, 70%, and 73%, respectively, of the total regional aircraft emissions of CO, HC, and NOx in 1970. This general relationship of emissions attributable to major airports and total regional aircraft emissions could be expected in similar highly populated air quality control regions.

In the Los Angeles region, uncontrolled emissions from aircraft are expected to account for 14% of the CO, 2.5% of the reactive HC, and 5.5% of the NOx total emissions by 1980.

Emissions from piston aircraft have a particularly significant impact on regional CO levels. Although piston aircraft were responsible for about 0.5% of the total CO emissions in 1970, their contribution to CO emissions, if uncontrolled, is expected to reach 10% by 1980.

SUB REGIONAL AND LOCALIZED IMPACT

This section deals with the effect of aircraft emissions on air quality at major airports and downwind of these airports. Emission densities and other parameters of emission intensity and air quality impact are first presented to provide indications of the contribution of aircraft to air pollutant concentration around a number of major U. S. airports. Then detailed results of sampling and dispersion modeling are presented to give deeper insight into the localized impact of aircraft at airports where aircraft contributions to air pollutant concentration are expected to be particularly important.

GENERAL INDICATORS OF LOCALIZED AIR QUALITY IMPACT

Passenger Usage Density and Air Pollution Potential-An indication of localized impact of aircraft on air quality is presented in Table 14 for the 20 largest U. S. air carrier airports, as determined by passenger enplanement. On the basis of concentration of passenger activity, proximity of the airport to built-up areas, and meteorological pollution potential[10] (a function of atmospheric mixing height and wind speed), seven airports, designated by asterisks in Table 14, could be expected to be particularly important contributors to localized air pollutant concentrations. The results of Table 14 indicate most directly the airport contributions to localized carbon monoxide concentrations; the airport contributions to oxidant and nitrogen dioxide concentrations are indicated less directly because intermediate atmospheric reactions are involved in their production.

Emission Density Comparison-Emission densities have been calculated for four of the airports that show a major air quality impact potential. Table 15 indicates that emission densities due to aircraft alone in 1970 were in most cases comparable to those of densely populated metropolitan areas served by the corresponding airports.

This emission density comparison suggests that, in these four airport areas, the contribution by aircraft to ambient air concentrations of hydrocarbon, CO, and NOx is substantial. Such contributions are particularly important where major airports lie in or near metropolitan areas in which national ambient air quality standards are currently exceeded. As shown in Table 5, this is the case for the four areas considered.

The comparison of emission densities (airport versus metropolitan area) for 1975 and 1980 demonstrates that the ratio of the airport emission densities to those of the metropolitan areas will increase in most cases, sometimes dramatically. The trends can be identified in Table 15, which indicates that aircraft are expected to become increasingly significant contributors to air pollutant concentrations at airports and in their vicinities.

It should be kept in mind that the emissions densities presented in Table 15 are averaged for the given areas and that variation in actual emission rates within the defined areas exist.

TABLE 14

INDICATIONS OF LOCALIZED AIRPORT IMPACT AT 20 LARGEST AIR CARRIER AIRPORTS

Airport	Enplaned Passengers Millions (FY 1970)	Aircraft Activity Percent Commercial Aviation	Percent General Aviation	Airport Area, Miles^2	$\frac{\text{Passengers}}{\sqrt{\text{area}}} \times 10^5$	Airport Proximity to Built-up Areas[a]	Morning Meteorological Air Pollution Potential $(\overline{\chi}/\overline{Q})$[b]
* O'Hare	13.5	95	5	14.1	36	2	50
* Los Angeles	8.5	76	22	4.8	40	2	50
* Atlanta	8.2	86	14	6.6	33	2	50
* J.F. Kennedy	7.0	86	14	8.1	25	2	30
* La Guardia	5.9	80	20	0.9	65	2	30
San Francisco	5.5	78	21	8.1	20	1	50
* Dallas (Love)	5.3	70	30	2.0	38	2	30
* Washington (Nat.)	4.9	66	33	1.0	49	2	70
Boston	4.5	66	34	3.7	24	1	20
Miami	4.4	66	31	4.2	22	2	20
Detroit	3.7	71	27	7.5	14		40
Denver	3.5	48	52	7.2	13	2	30
Newark	3.4	76	24	3.4	19	2	30
Philadelphia	3.2	70	30	3.9	17	2	30
St. Louis	3.1	58	38	2.9	18	2	40
Pittsburgh	3.0	64	29	4.8	14		80
Minneapolis	2.6	55	37	4.6	13	2	60
Cleveland	2.5	45	55	2.3	17		50
Seattle	2.5	68	32	2.8	16	2	40
Houston	2.2	73	27	11.4	6	1	30

---

[a] 1 = Residential and business areas adjacent to airport boundaries.
2 = Residential and business areas adjacent to airport boundaries, and a significant frequency of wind from airport toward these areas.

[b] This parameter is based on a simple model of dispersion over urban areas, in which an average area-wide pollutant concentration, $\overline{\chi}$, is normalized for an average emission rate, $\overline{Q}$. High $\overline{\chi}/\overline{Q}$ values indicate high potential pollutant concentrations. The values listed above are morning upper decile levels for a 10-kilometer along-wind distance. More detailed information on this parameter is presented in Ref. 10.

Table 15. COMPARISON OF EMISSION DENSITIES FOR AIRPORTS VERSUS URBAN AREAS FOR 1970, 1975, and 1980

	Area,[a] mi^2	Emission densities,[b] tons/mi^2-day								
		1970			1975			1980		
		Carbon monoxide	Hydro-carbons	Nitrogen oxides	Carbon monoxide	Hydro-carbons	Nitrogen oxides	Carbon monoxide	Hydro-carbons	Nitrogen oxides
Los Angeles metropolitan area	1250.0	7.2	2.0	1.0	4.8	1.1	0.9	2.8	0.9	0.8
Los Angeles Airport - all emission sources	3.9	20.6	10.3	2.0	20.2	7.4	3.5	19.1	4.0	5.6
Los Angeles Airport - aircraft alone	3.9	11.2	8.8	1.1	11.7	6.1	2.6	13.0	3.4	4.9
New York metropolitan area	320.0	14.5	3.4	3.6	11.4	2.4	3.6	5.5	1.3	3.2
Airport - all emission sources	4.5	19.6	7.7	2.1	16.2	4.9	2.7	11.2	2.4	3.0
Airport - aircraft alone	4.5	7.7	5.8	0.8	6.9	3.5	1.5	6.5	1.7	2.3
Washington D.C. metropolitan area	61.0	12.5	1.7	1.7	7.9	1.1	1.5	3.3	0.4	1.3
National Airport - all emission sources	1.0	10.2	2.4	1.7	10.1	2.3	1.8	9.5	2.1	1.9
National Airport - aircraft alone	1.0	6.6	1.7	1.0	7.4	1.9	1.2	8.3	2.0	1.4
Chicago metropolitan area	227.0	8.1	2.5	1.4	6.3	1.7	1.4	1.4	0.9	1.2
O'Hare Airport - all emission sources	6.7	14.1	5.4	1.9	12.9	3.6	2.0	9.1	2.0	2.3
O'Hare Airport - aircraft alone	6.7	6.0	3.9	0.8	5.7	2.6	1.3	5.5	1.5	1.8

[a] Airport areas represent those areas devoted to the operation of the airport, but not necessarily the total area owned by the airport.

[b] Emissions used to calculate airport emission densities are based on all aircraft emissions within each airport area.

The majority of the HC, CO, and NOx emissions in metropolitan areas are due to area rather than point sources. This tends to minimize variation in emission densities throughout a metropolitan area. However, one would expect to observe higher emission densities where there is high population activity such as in downtown and industrial areas as opposed to residential areas within the region.

Detailed Investigation of Localized Pollutant Concentrations

The emissions density data previously discussed pointed to the fact that major airports are and will continue to be significant area sources of air pollution emissions. If the health and welfare of the exposed population is to be protected, the conclusion may be drawn that the emissions must be reduced equally for all such sources, e.g., whether they be airport or non-airport area sources of pollution.

8-Hour Carbon Monoxide Concentrations-Carbon monoxide concentrations at the Los Angeles International Airport and in its vicinity were measured from May to November, 1970.[2] The sampling was done by the Los Angeles County Air Pollution Control District under EPA contract. Carbon monoxide concentrations were continuously monitored at several sampling sites, including 4 sites in the airport terminal area, and at 2 sites located upwind and downwind of the airport complex. At all of these, ambient concentrations of CO were measured. The monitoring sites were located as shown in Figure 1. Data from site 209 were analyzed extensively to determine as quantitatively as possible the air quality impact of aircraft CO emissions on 8-hour ambient CO concentrations in residential and business areas downwind of the airport.

Site 209 is located directly downwind of the L.A. airport when the wind blows from its most frequent direction, as indicated by the wind rose in Figure 1. Until recently this area was a residential neighborhood, but now it is almost completely owned by the Los Angeles Airport. Other residential areas, however, are located only a few blocks west and north of this area; and it was concluded that concentrations measured at site 209 are indicative of concentrations in such residential areas.

Figure 2 presents an estimated frequency distribution of carbon monoxide concentrations at site 209 during the winter months, the time of highest CO concentrations in the Los Angeles area. This frequency distribution is based on sampling data collected at site 209 during August and is adjusted to represent wintertime concentrations using a seasonal conversion based on air quality data for the entire Los Angeles basin. Derivation of the results shown in Figure 2 is detailed in Appendix A. It can be seen, in Figure A-3 of that section, that site 209 is exposed to the same levels of carbon monoxide whether it be influenced by pollution from other than the airport (easterly winds) or from the airport alone (westerly winds). Figure 2 shows that the 8-hour CO standard, which is not to be exceeded more than once per year, is estimated to have been exceeded at site 209 13 times per month, or 39 times in the winter 3-month period.

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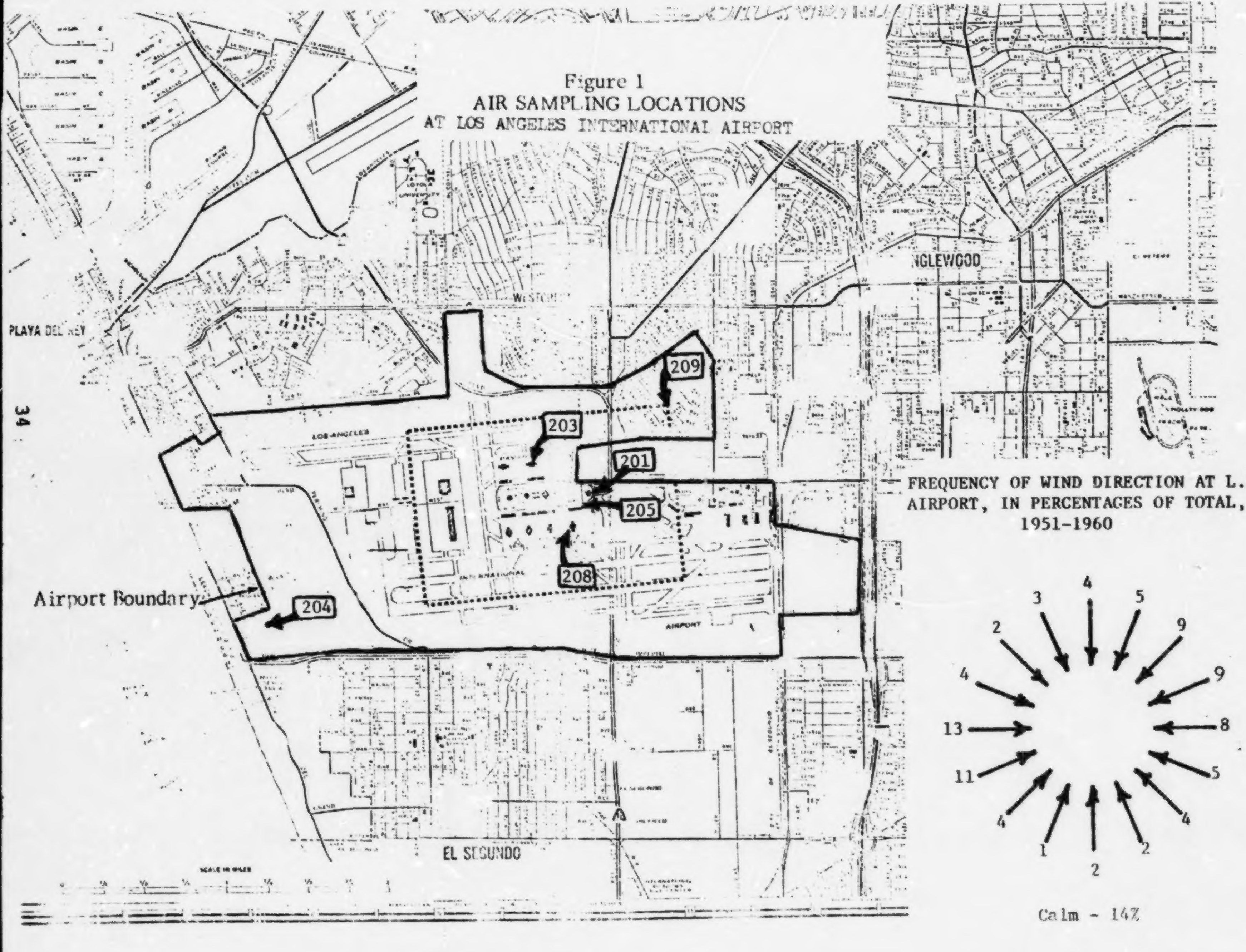


Figure 1
AIR SAMPLING LOCATIONS
AT LOS ANGELES INTERNATIONAL AIRPORT

PLAYA DEL REY
WESTCHESTER
INGLEWOOD
EL SEGUNDO
LOS ANGELES
INTERNATIONAL
AIRPORT
Airport Boundary
209
203
201
205
208
204
SCALE IN MILES

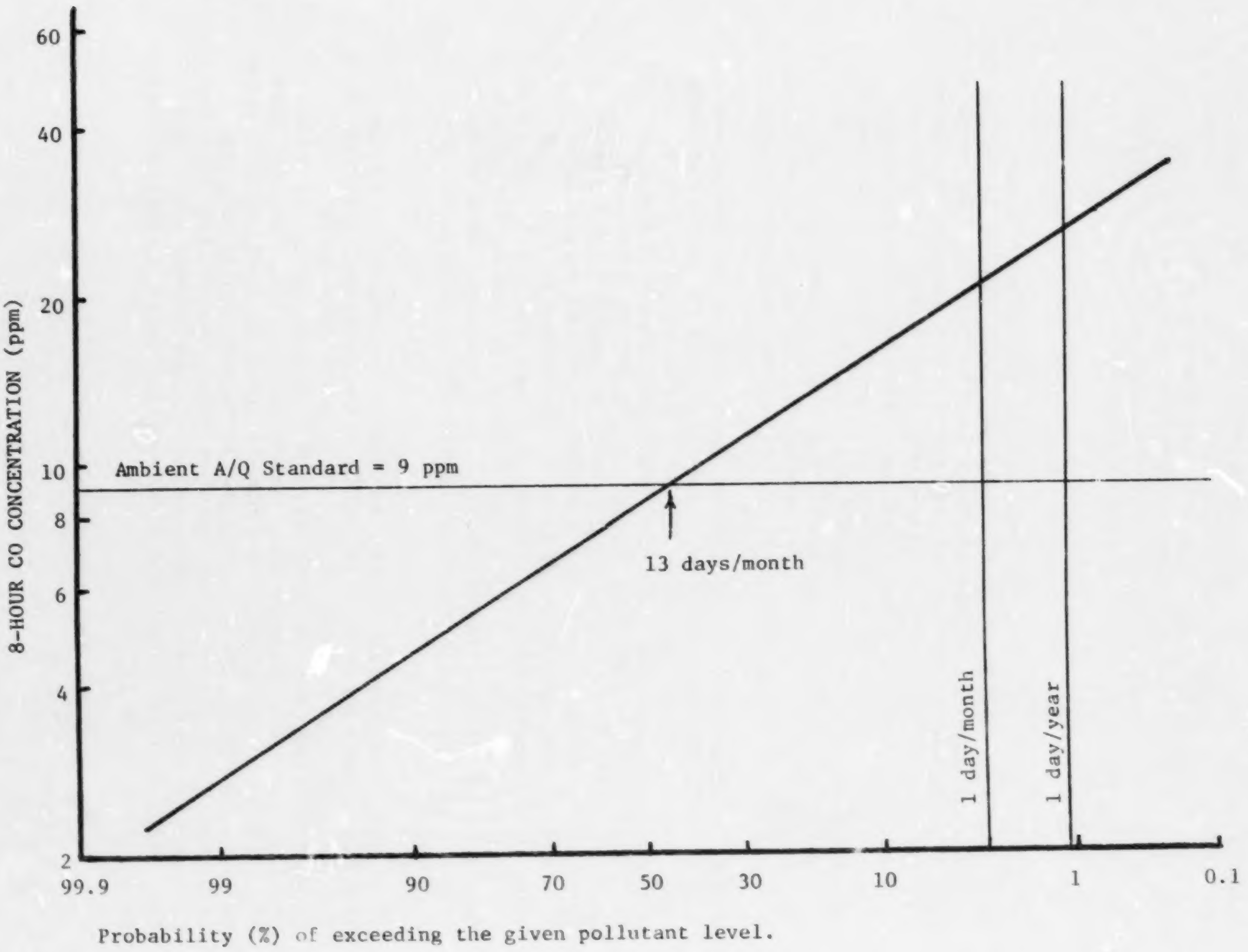
FREQUENCY OF WIND DIRECTION AT L.A. AIRPORT, IN PERCENTAGES OF TOTAL, 1951-1960

4
5
9
9
8
5
4
2
2
1
4
11
13
4
2
3

Calm - 14%

FIGURE 2

EXPECTED CO CONCENTRATIONS, 8-HOUR AVERAGING TIME, WINTER 1970, STATION 209, LAX



Part of the carbon monoxide concentrations shown in Figure 2 are due to aircraft. To estimate the portion of the concentration that is due to aircraft, dispersion modeling was applied. The dispersion modeling methodology is discussed in Appendix B. The model's resulting estimate of the current contribution by aircraft to total CO concentrations, shown in Figure 3, indicates that aircraft are highly significant contributors to local CO concentrations downwind of the airport. Figure 3 indicates that expected aircraft contributions constitute 60-70% of the total CO concentrations in the area of site 209.

Between 1970 and 1980, CO emissions from aircraft are estimated to increase by fifteen per cent (Table 4) while CO emissions from all other sources in the Los Angeles area are expected to decrease to 20% of their 1970 levels.[12] Using the estimated changes in emissions from these two source categories, and assuming that the emission changes yield proportional changes in pollutant concentrations due to each source category, CO concentration frequency distributions for various aircraft contributions can be derived from Figure 2. The result is presented in Figure 4 for various 1970 aircraft contributions to pollutant concentrations.

Figure 4 indicates that without controls of CO emissions from aircraft the 8-hour CO standard will be exceeded more than once during the 1980 winter months at site 209 if the aircraft contribution to the total CO concentration in 1970 is as little as 20%. As shown in Figure 3, the 1970 contribution by aircraft exceeds this percentage over a large area downwind of the airport. If the reasonable assumption is made that Figure 2 approximates the 1970 winter CO concentration frequency distribution in this area, it is evident that in 1980 the 8-hour CO concentrations will continue to exceed the standards in this same area downwind of the Los Angeles Airport if aircraft CO emissions are not controlled.

As noted in Appendix A, the analysis resulting in Figures 2 and 4 can be repeated using data from September, rather than from August, as a basis. The September data will yield higher concentrations than will the August data for similar frequencies of occurrence. Consequently, the results from the September data analysis can be used to indicate an upper value of a range of frequencies at which the 8-hour CO standard is exceeded; the results from the August data can be used to indicate a lower value of the range. The ranges for 1970, and for 1980 with various aircraft contributions, is presented in Table 16.

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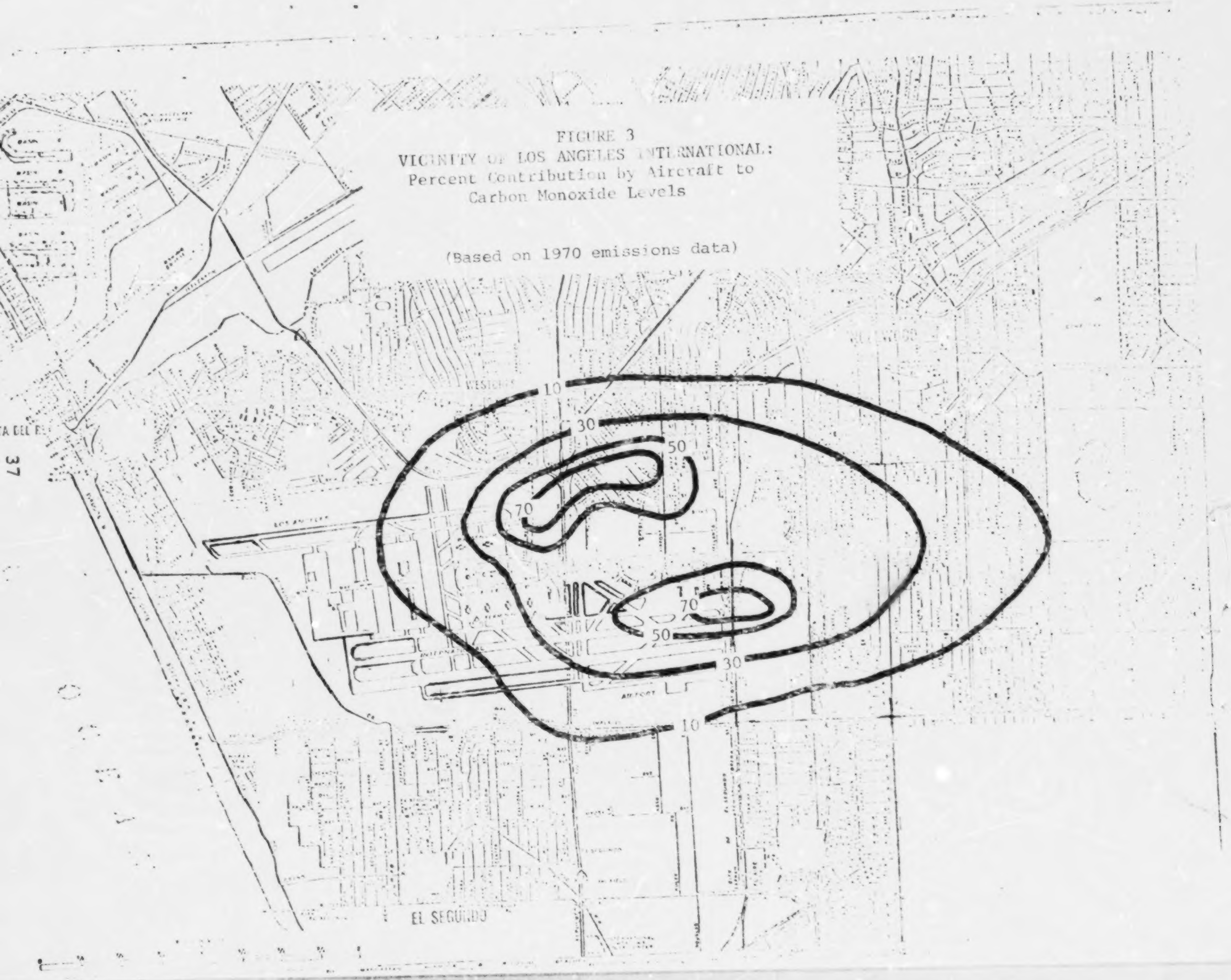
10
30
50
70
70
50
30
10
EL SEGUNDO

FIGURE 3
VICINITY OF LOS ANGELES INTERNATIONAL:
Percent Contribution by Aircraft to
Carbon Monoxide Levels

(Based on 1970 emissions data)

FIGURE 4
FREQUENCY DISTRIBUTIONS FOR CARBON MONOXIDE FOR VARIOUS
AIRCRAFT EMISSION CONTRIBUTIONS AT STATION 209 - WINTER 1980

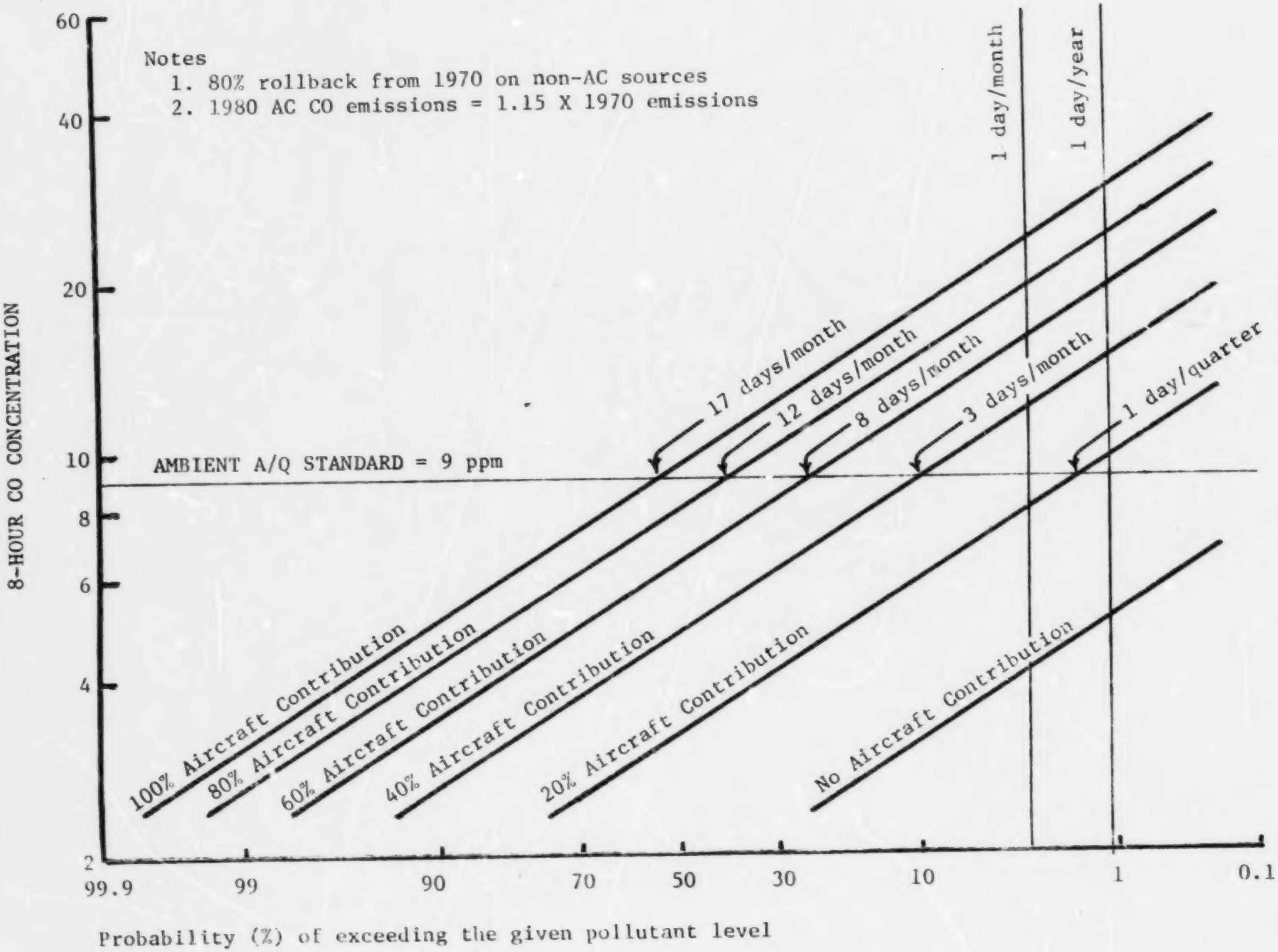

TABLE 16

EXPECTED RANGE OF DAYS THAT 8-HR STANDARD WILL BE EXCEEDED IN VICINITY OF L.A. AIRPORT, 1970 and 1980[a]

	Based on August Data[b]		Based on September Data
Days Standard Exceeded in 1970	39	to	65
Days Standard Exceeded in 1980, With Following % Contributions by Aircraft (at 1970 emission levels) to Total CO Concentrations			
80%	36	to	61
60%	22	to	49
40%	9	to	32
20%	1	to	14
0%	0	to	1

---

[a] Because the highest CO concentrations occur during winter months, it is assumed that the frequency of exceeding the standard during the winter quarter gives the frequency of exceeding the standard the entire year.

[b] From Figures 2 and 4.

1-Hour CO Concentrations at the Los Angeles Airport-The 1-hour CO air quality standard of 35 ppm (40 ug/m3) was exceeded at only one of the outdoor continuous sampling locations at the Los Angeles Airport. A summary of the 1-hour sampling data at these receptors is presented in Table 17, which indicates that only at site 205 was the 1-hour CO standard frequently exceeded. Site 205 was located next to heavy automobile traffic on World Way Boulevard at an automobile passenger unloading area. The 1-hour CO standard was exceeded 12 times during the approximately 4-week period of sampler operation. Expected reductions in CO emissions from automobiles probably would reduce concentrations at sites such as 205 to levels below the 1-hour standard. Generally the 8-hour CO standard of 10 ug/m3 is the most difficult of the two standards to reach, and statistically if the 8-hour standard is met, the 1-hour CO standard will also be met.[13]

Carbon Monoxide Concentrations at Other Airports-Dispersion modeling was used to provide estimates of 1-hour CO concentrations both from aircraft alone and from all airport and adjacent sources within 10 kilometers of the center of each airport. This modeling was done for Los Angeles, J. F. Kennedy, Chicago-O'Hare, and Washington National Airports. The results, presented in Table 18, are predicted concentrations at airport area points where:
(1) The general public could have access for 1-hour periods, and (2) the total concentrations, as estimated by dispersion modeling, exceed the standards.

Although minimal reliance should be placed on the precise numerical values predicted by the model, these values are of the same order of magnitude as the values from actual measurements presented in Table 17. These results indicate that localized carbon monoxide effects are not limited to Los Angeles Airport.

The potential of high 8-hour CO concentrations downwind of other airports, with large aircraft contributions, exists near airports besides Los Angeles Airport. As previously discussed, Table 14 indicates the potential of such concentrations at six additional airports.

Hydrocarbon and Potential Oxidant Concentrations-Isopleths of 1970 hydrocarbon concentrations due to aircraft alone at the Los Angeles Airport are presented in Figure 5. These isopleths are based on the dispersion modeling methodology presented in Appendix B, and are a result of meteorological conditions that are particularly conducive to high

TABLE 17

LOS ANGELES AIRPORT

NUMBER OF TIMES THE 1-HOUR CO STANDARD WAS EXCEEDED MAY 10 THROUGH NOVEMBER 9, 1970, CONTINUOUS SAMPLING SITES

Site*	Total Hours of Sampling	Number of Hourly Values When Standard Exceeded	Highest Two Hourly Values
201	3710	0	27, 26
203	4256	2	46, 40
204	4258	0	23, 19
205	637	12	51, 49
208	4326	1	37, 28
209	4279	0	31, 27
Downtown LA	4965	3	37, 35

*Refer to Figure 1 for Location.

Table 18

Dispersion Model Estimates of 1-Hour Carbon Monoxide Concentrations

Site Location*	CO Concentration, mg/m^3	
	Aircraft Sources Only	Total
JFK (T)	85	100
JFK (T)	4	45
JFK (T)	3	44
LAX (P)	55	62
LAX (P)	32	45
ORD (T)	21	41
ORD (S)	9	41
DCA (P)	110	120
DCA (P)	45	59

*DCA = Washington National Airport, LAX = Los Angeles International Airport, JFK = John F. Kennedy International Airport, and ORD = O'Hare Airport, Chicago

(T) = Terminal area

(P) = Peripheral area--away from terminals, but within airport boundary

(S) = Outside of airport boundary, in airport surroundings

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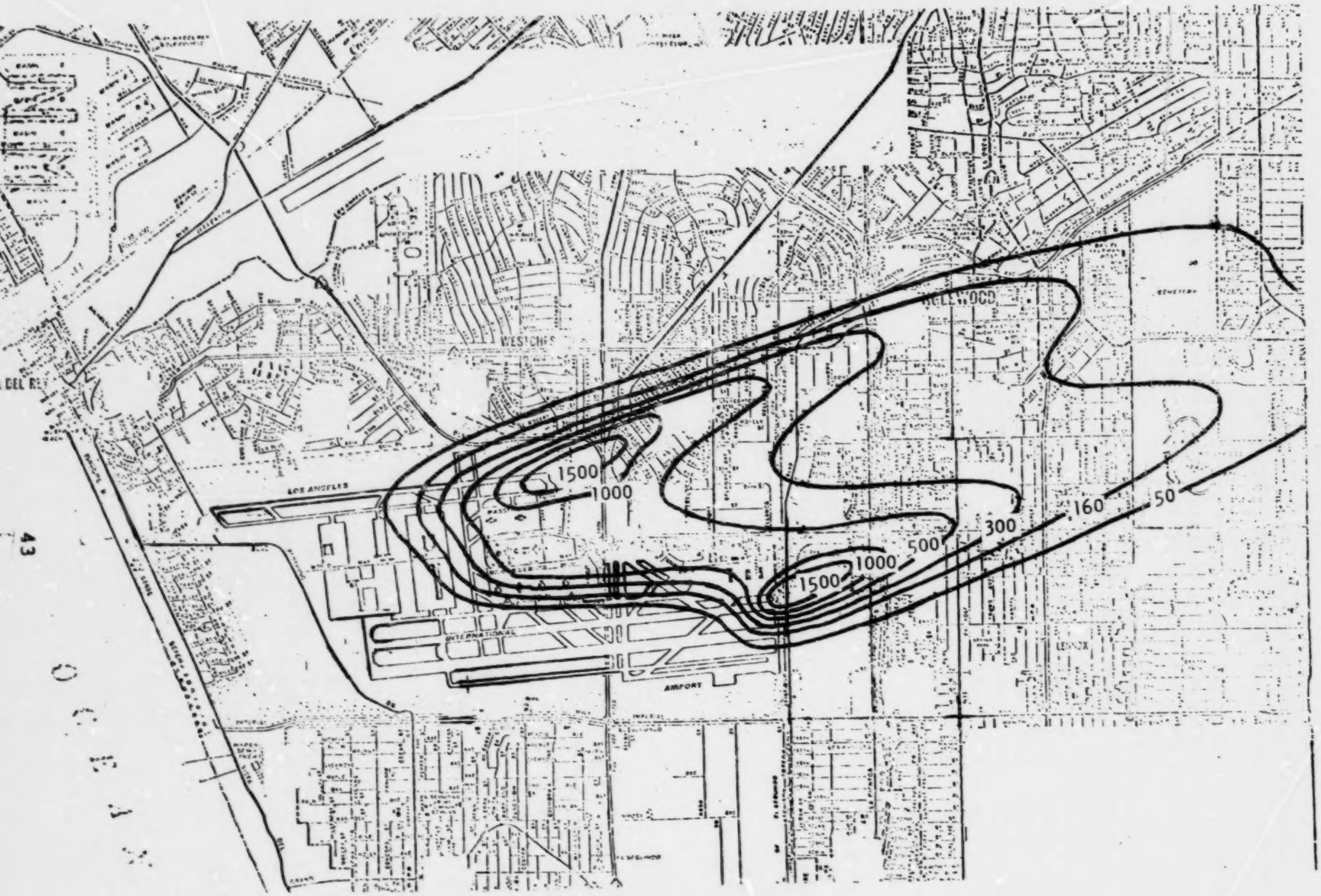
50
160
300
500
1000
1500
1000
1500
LOS ANGELES
INTERNATIONAL
AIRPORT
WESTCHES
LENNOX
DEL REY
OCEAN

(numbers in $\mu g/m^3$)

FIGURE 5 HYDROCARBON ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES

3-Hr Average for 1970 (6 - 9 AM)

hydrocarbon concentrations. Such conditions would be expected to occur at least once per year.

The results indicate that there are large areas surrounding the airport where the hydrocarbon concentrations due to aircraft are well in excess of the standard.

Between 1970 and 1980, Table 4 indicates that at the Los Angeles Airport, hydrocarbon emissions from aircraft will decline to about 40% of their 1970 values. These reductions are reflected in Figure 6 which presents isopleths of 1980 hydrocarbon concentrations due to aircraft alone, at Los Angeles Airport, based on meteorological conditions equivalent to those used for the isopleths in Figure 5. Even with the reduction in aircraft hydrocarbon emissions, it is likely that in 1980 the hydrocarbon standard will continue to be exceeded over a large area due to aircraft emissions alone.

As indicated earlier, hydrocarbon concentrations at levels typically found in the atmosphere are not harmful to health. However, if airport hydrocarbon concentrations were followed downwind for several hours under conditions conducive to the accumulation of high oxidant concentrations,[7] aircraft-generated hydrocarbons could be expected to be large contributors to downwind oxidant concentrations over the Los Angeles area.

A modeling analysis was performed to estimate hydrocarbon concentrations downwind of Los Angeles Airport in 1980. The meteorological conditions used were similar to those used for Figures 5 and 6. The methodology of this analysis is presented in Appendix C, and results are presented in Figure 7. The three curves in Figure 7 show nonmethane hydrocarbon concentrations downwind of Los Angeles Airport resulting from the surroundings plus total airport emissions, total airport emissions alone, and aircraft emissions alone. The initial concentration at the western airport boundary (0 km in Figure 7) is shown to be zero, which is a result of the proximity of the western boundary to the ocean, wind direction from the west, and the assumption of negligible hydrocarbon concentrations in wind coming off at the ocean. At a point 3 hours downwind (16 km from the eastern airport boundary) the overall hydrocarbon concentration will have been in excess of the standard for 3 hours, enough time for possible formation of oxidant in concentrations exceeding the standard.

It is important to emphasize that this analysis was performed for 1980. If it were repeated for 1970, the

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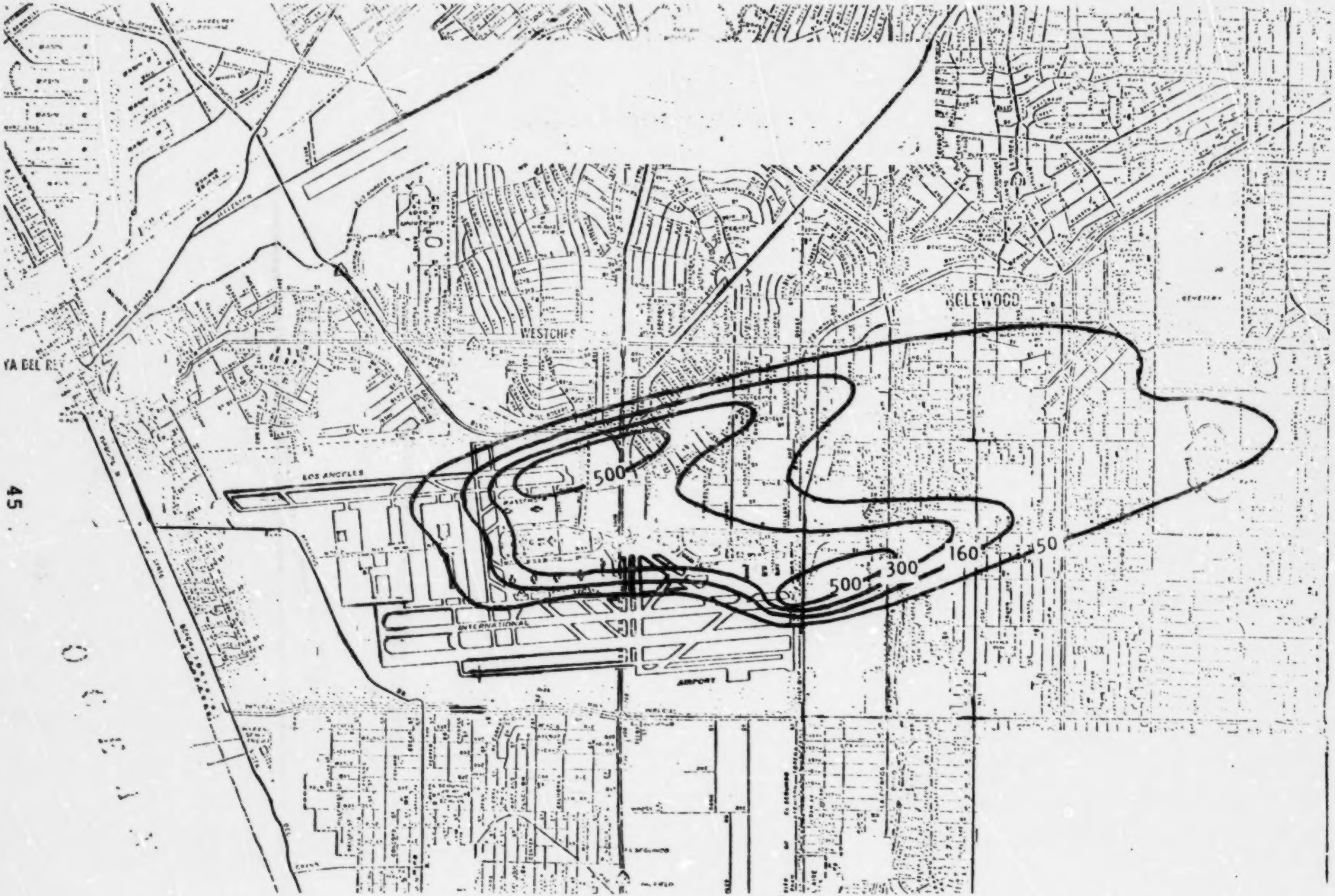

YA DEL REY
WESTCHES
NGLEWOOD
LOS ANGELES
INTERNATIONAL
AIRPORT
LENNOX
500
500
300
160
50
O C E A N

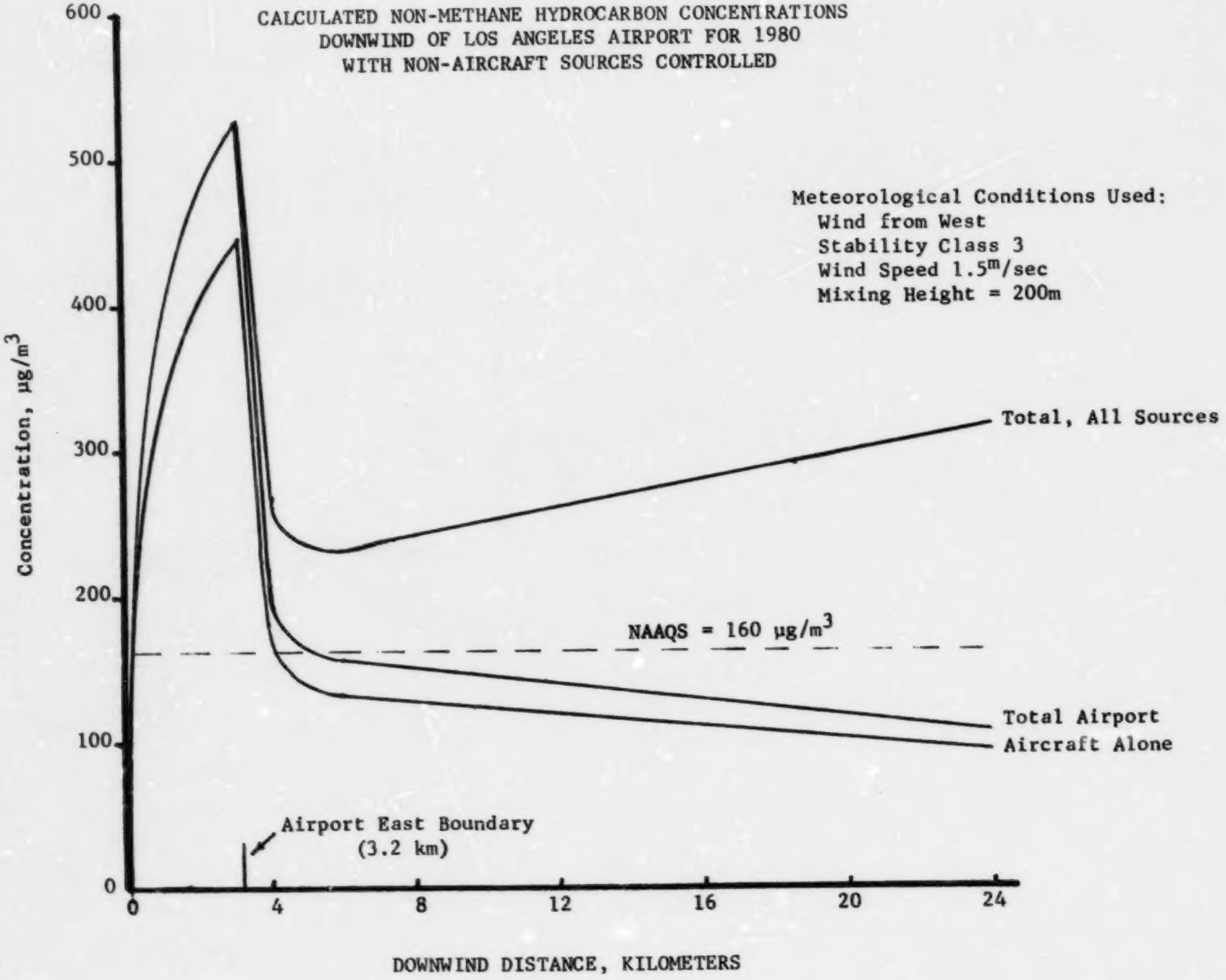
(numbers in $\mu g/m^3$)

FIGURE 6 HYDROCARBON ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES

3-Hr Average for 1980 (6 - 9 AM)

FIGURE 7

CALCULATED NON-METHANE HYDROCARBON CONCENTRATIONS
DOWNWIND OF LOS ANGELES AIRPORT FOR 1980
WITH NON-AIRCRAFT SOURCES CONTROLLED



Meteorological Conditions Used:
Wind from West
Stability Class 3
Wind Speed 1.5^m/sec
Mixing Height = 200m

concentrations for each of the curves would be at least double the 1980 values.

The emissions densities presented in Table 15 indicate that among the four airports studied, emission densities from aircraft alone are highest at Los Angeles Airport. However, the range among these emission density values is still less than a factor of 2.3 in 1980, indicating that conclusions concerning future aircraft-generated hydrocarbon and oxidant concentrations at the Los Angeles Airport and vicinity apply generally to the other airports studied, and that additional reductions in aircraft-generated hydrocarbon concentrations are necessary.

Oxides of Nitrogen-Although the ambient air quality standard is for NO2 (100 ug/m3, annual concentration), the result of the dispersion modeling is presented as oxides of nitrogen (NOx). This is done because there exists no well-defined relationship for the conversion of NO to NO2. In the presence of hydrocarbons; the NO to NO2 conversion is accelerated; best estimates indicate that 90 percent of the NO is converted to NO2 within a 2-hour period in the presence of sunlight. The reaction is essentially negligible at night. Considering all NOx as NO2 could result in an overestimation of annual average concentrations.

Oxides of nitrogen concentrations due to aircraft alone are presented in Figure 8 for Los Angeles Airport area for 1970. These modeling approximations indicate that LAX is responsible for NOx impact over a large area surrounding the airport. With growth of overall aircraft activity, and the changeover to bigger and higher pressure ratio turbine engines, aircraft emissions of NOx will increase greatly between 1970 and 1980. Present and expected future NOx emissions from aircraft at the four major airports studied are given in Table 15, which indicates that between 1970 and 1980 aircraft emissions of NOx will increase by factors of 2.2 at O'Hare Airport, 1.4 at Washington National Airport, 4.5 at Los Angeles International Airport, and 2.9 at John F. Kennedy Airport.

The general affect of increased NOx emissions from aircraft at LAX is reflected in Figure 9, which presents isopleths of 1980 NOx concentrations due to aircraft. Figure 9 indicates that NOx concentrations due to aircraft alone could be widespread in residential areas around LAX, and that in some areas, the NO2 concentrations due to aircraft are comparable with the standard. It should be emphasized that these NOx concentrations are due to aircraft alone, and NOx emissions

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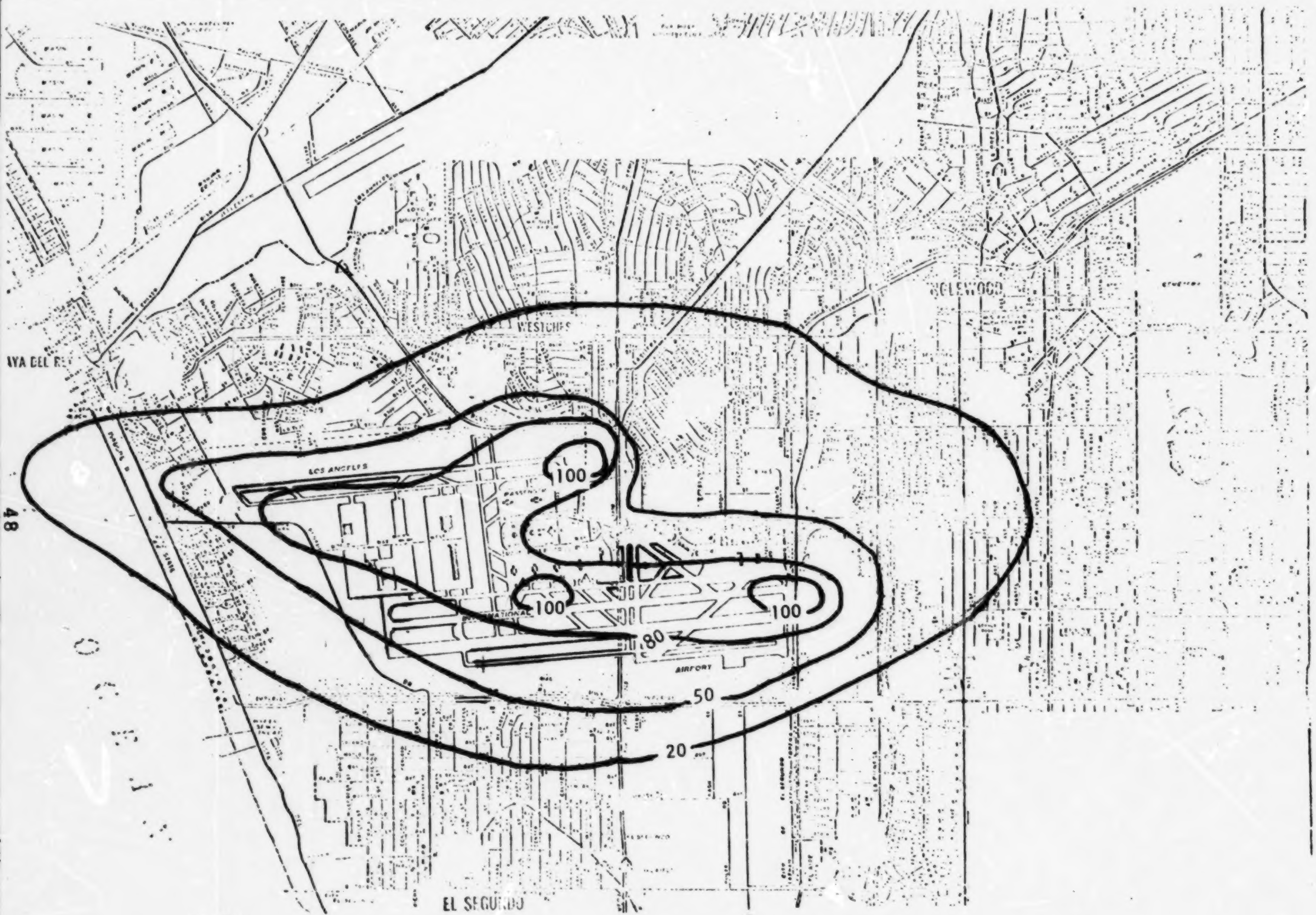
NGLEWOOD
WESTCHES
YA DEL RE
LOS ANGELES
INTERNATIONAL
AIRPORT
EL SEGUNDO
100
100
100
100
80
50
20

(numbers in $\mu g/m^3$)

FIGURE 8 NO_x ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES
Annual Average for 1970

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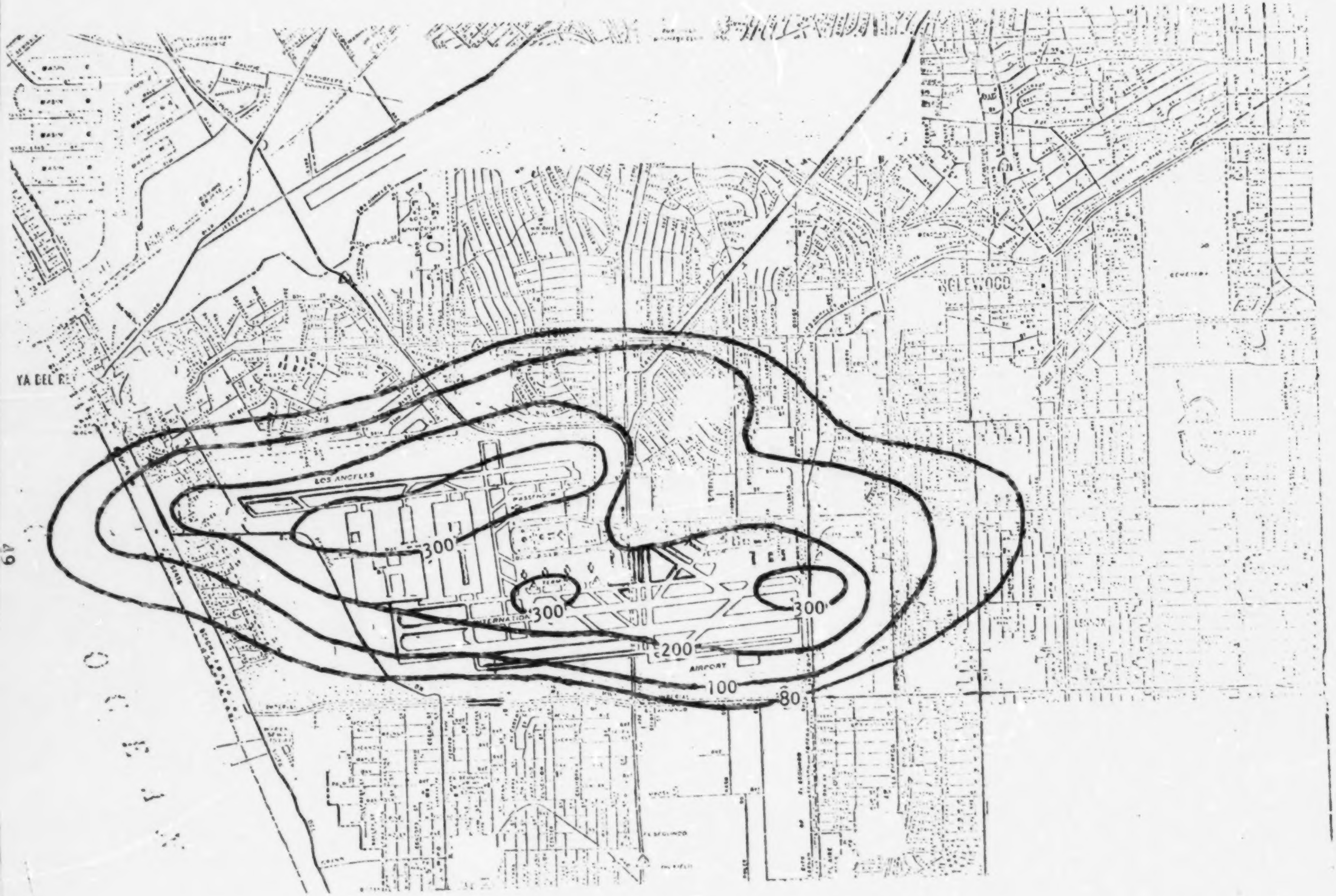
YA DEL R
LOS ANGELES
INTERNATIONAL
AIRPORT
GLEWOOD
O C E A N
300
300
300
300
200
100
80

(numbers in $\mu g/m^3$)

FIGURE 9 NO_x ISOPLETHS IN THE VICINITY OF LOS ANGELES INTERNATIONAL: AIRCRAFT SOURCES
Annual Average for 1980

from other sources would be expected to significantly increase the concentrations plotted in Figures 8 and 9.

NOx concentrations of similar magnitude to those in Figures 8 and 9 can be expected in the vicinity of other airports. For example, isopleths showing expected 1980 NOx emissions densities due to aircraft alone for O'Hare Airport are presented in Figure 10. Without emission controls, aircraft using O'Hare Airport can be expected to be large future contributors to localized NOx concentrations, as was the case for Los Angeles Airport.

Smoke and Particulates. Smoke generated by aircraft causes significant reductions in visibility and is a cause of widespread complaint by affected citizens.

The 1-year air quality monitoring program conducted at Los Angeles International Airport indicated increased soiling effects in the airport vicinity due to aircraft activity. Atmospheric measurements of particulates using a tape sampler technique gave higher readings (indicative of soiling) for the airport area than for locations several miles removed, such as downtown Los Angeles. Additionally, sampling at sites surrounding and adjacent to the Los Angeles Airport area showed increasing soiling values from upwind of the airport to a maximum immediately downwind of the airport.

Measurement of total weight of particulate material, based on Hi-Vol sampling, showed little variation between airport and downtown areas.

Results of the dispersion modeling analysis for all four airports indicated that particulate concentrations due to aircraft in some parts of the airports could exceed the secondary particulate air quality standards.

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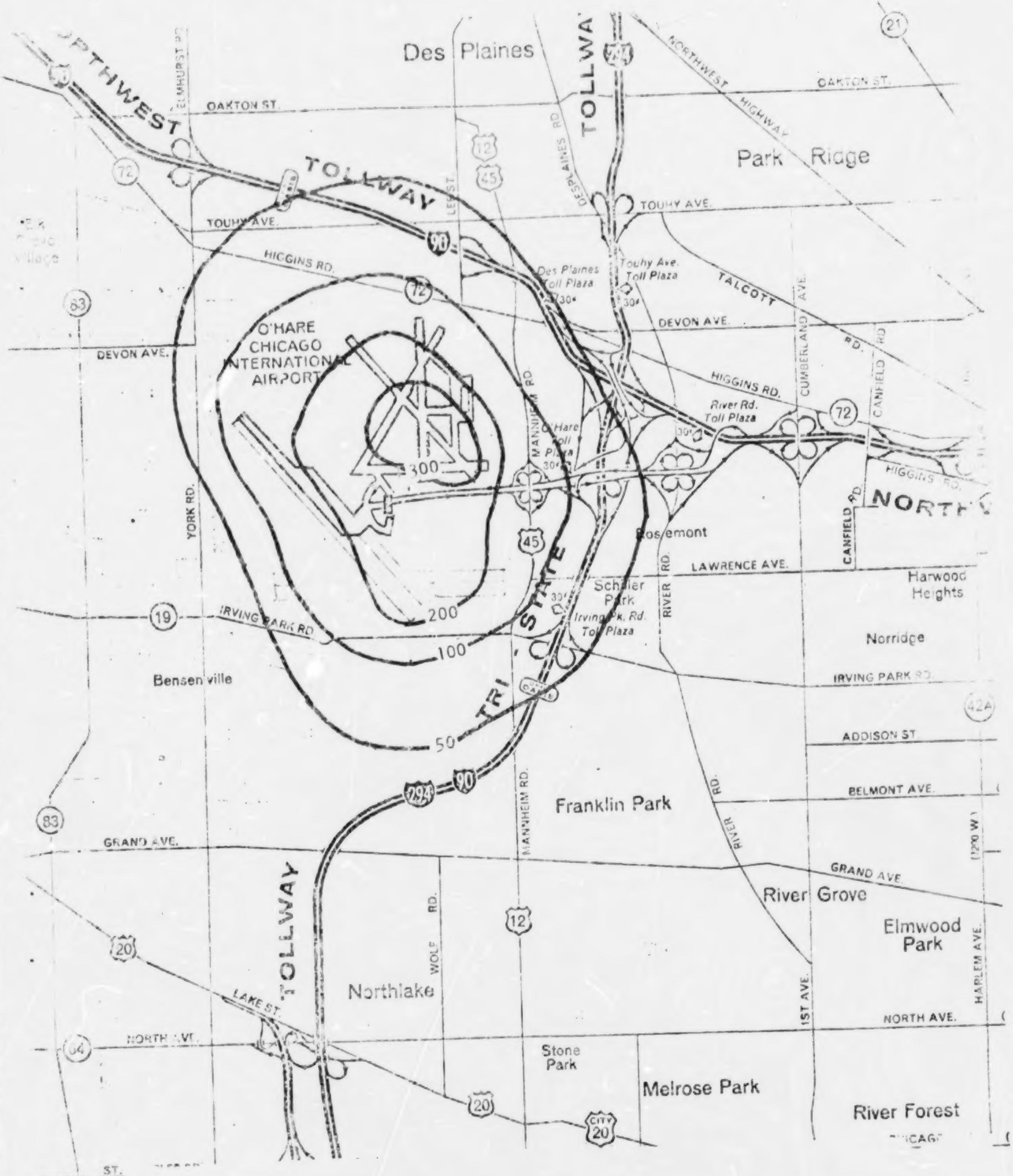
Des Plaines
NORTHWEST TOLLWAY
TOLLWAY
OAKTON ST.
NORTHWEST HIGHWAY
Park Ridge
ELMHURST RD.
DESPLAINES RD.
LEE ST.
TOUHY AVE.
HIGGINS RD.
Elk Grove Village
Des Plaines Toll Plaza
Touhy Ave. Toll Plaza
TALCOTT RD.
DEVON AVE.
O'HARE CHICAGO INTERNATIONAL AIRPORT
MANNHEIM RD.
CUMBERLAND AVE.
CANFIELD RD.
River Rd. Toll Plaza
O'Hare Toll Plaza
300
200
100
50
NORTH
Rosemont
YORK RD.
LAWRENCE AVE.
Harwood Heights
Schiller Park
RIVER RD.
Irving Pk. Rd. Toll Plaza
Norridge
IRVING PARK RD.
TRI-STATE
Bensenville
ADDISON ST.
BELMONT AVE.
Franklin Park
GRAND AVE.
River Grove
Elmwood Park
HARLEM AVE.
1ST AVE.
WOLF RD.
Northlake
LAKE ST.
NORTH AVE.
Stone Park
Melrose Park
River Forest
21
72
83
90
294
45
12
19
20
42A
64
CITY 20

FIGURE 10 (numbers in $\mu g/m^3$)

NO_x ISOPLETHS IN THE VICINITY OF CHICAGO-O'HARE INTERNATIONAL: AIRCRAFT SOURCES

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TECHNOLOGICAL FEASIBILITY OF CONTROLLING AIRCRAFT EMISSIONS

Information on emission control methods is necessary to determine the levels to which aircraft emissions can feasibly be reduced. An earlier Federal study,[1] [14] identified potential control approaches including modification of aircraft engines, fuels, and ground operational procedures. This study indicated that modification of aircraft engines and ground operational procedures appear to be the most feasible and effective control procedures. More recently, the Aerospace Industries Association (AIA) has issued a report[15] summarizing results of investigations conducted by industry on: (1) emission characteristics of aircraft gas turbine engines; and (2) potential methods for reducing aircraft turbine engine emissions. The AIA report also identifies the possibility of reducing emissions through modifications of engines (especially combustor design) and of ground operational procedures.

The current reassessment of control methods must consider each of the aforementioned approaches. In assessing the feasibility of a control method, four factors must be explored: (1) effect of the method on the functioning or capacity of the aircraft system; (2) effectiveness of the method in reducing emissions; (3) cost of utilizing the method; and (4) time required for implementing the method. Information on emission-measurement instrumentation is also necessary to ensure that aircraft emissions can be measured with the accuracy and sensitivity required for enforcing the desired standards.

The Environmental Protection Agency has conducted several studies (references 16-27) to obtain information for assessment of aircraft emission control methods. This report summarizes the information obtained in these investigations. The specific objectives of this analysis of aircraft emission control technology are:

(1) To identify methods of controlling aircraft emissions through modification of engines, fuels, and ground operations.

(2) To estimate their effectiveness in reducing aircraft emissions.

(3) To estimate the time required for and cost of implementation.

(4) To assess the technology of measuring emissions from aircraft engines and to identify areas requiring advancements in instrumentation or test procedures.

Emission control by fuel modifications was reassessed to evaluate developments in aircraft fuel technology. This investigation was discontinued after preliminary analysis indicated that no significant reductions in emissions could be achieved by modifying fuels, except for reductions in sulfur or lead content that result in proportionate reductions of SO_2 and lead emissions.

A list of specific emission control methods involving engine modifications was formulated on the basis of preliminary analyses, which indicated that each method was feasible and offered a significant reduction in one or more emission classes. Feasibility was assessed on the basis of the following factors:

(1) No reduction in engine reliability (safety).

(2) Little or no reduction in engine performance (power-weight ratio).

(3) Reasonable cost of implementation.

The preliminary list of control methods was then subjected to more detailed analysis of control effectiveness and implementation costs. Control methods involving changes in ground operations were evaluated in a similar manner.

Evaluation of the emission control methods involving engine modifications gave primary consideration to the following emission classes: carbon monoxide (CO), nitrogen oxides (NOx), total hydrocarbons (including drained fuel) (THC), dry particulates (DP), and smoke.

EMISSION CONTROL BY ENGINE MODIFICATION

Engine Classification

To facilitate analyses of engine modifications, aircraft engines are categorized according to their thrust or power level. The classification system is indicated in Table 19.

TABLE 19

AIRCRAFT ENGINE CLASSIFICATION

Engine class	Engine Type	Power Range, lb thrust or eshp
T1	Turbine	Less than 6,000
T2	Turbine	6,000 to 29,000
T3	Turbine	Greater than 29,000
P1	Piston	All piston engines

Although this classification system is based simply upon power level it effectively groups engines of similar emission potential (when the emission rates are normalized according to an appropriate engine-size parameter). Also, since effectiveness factors and costs of the control methods are similar for engine models within each class, the system is particularly useful for this analysis.

Three classes of turbine engines are defined, and all piston engines are included in a single class. This system thus categorizes engines according to their principal applications and according to certain design characteristics that affect emission rates.

The small turbine engine class (T1) includes most of the turboshaft and small turbojet and turbofan engines used in business and small commercial aircraft. It also includes auxiliary power units (APU) used on large commercial aircraft. These engines are considered as one class because the relatively small size of the combustor components (or large surface-volume ratio) makes control of certain emissions more difficult than with larger engines.

The next turbine engine class (T2) includes most of the turbojet and turbofan engines used in medium-to-large commercial aircraft. The design characteristics of most of these engines are basically similar.

The third turbine engine class (T3) includes large turbofan engines for "jumbo" transport aircraft and the SST engines currently in use or under development.

Emission Control Methods and Effectiveness

Technology for controlling emissions from aircraft engines by means of engine modifications has been analyzed. The purpose of this analysis was to identify specific methods of reducing pollutant emissions from aircraft engines and to indicate the reductions in rates of emission attainable by these methods. Various engine modifications appear to be feasible in that they can be applied to aircraft without degrading engine reliability or seriously reducing aircraft performance. Costs of implementing these control methods also appear to be within reasonable limits, at least in preliminary analysis.

Turbine Engines - The engine modification control methods considered feasible for turbine engines are listed and described briefly in Table 20. Six methods are, at least in

Table 20. ENGINE MODIFICATIONS FOR EMISSION CONTROL FOR EXISTING AND FUTURE TURBINE ENGINES

Control method	Modification
Existing engines	
t1 - Minor combustion chamber redesign	Minor modification of combustion chamber and fuel nozzle to achieve best state-of-art emission performance.
t2 - Major combustion chamber redesign	Major modification of combustion chamber and fuel nozzle incorporating advanced fuel injection concepts (carburetion or prevaporization).
t3 - Fuel drainage control	Modify fuel supply system or fuel drainage system to eliminate release of drained fuel to environment.
t4 - Divided fuel supply system	Provide independent fuel supplies to subsets of fuel nozzles to allow shutdown of one or more subsets during low-power operation.
t5 - Water injection	Install water injection system for short duration use during maximum power (takeoff and climb-out) operation.
t6 - Modify compressor air bleed rate	Increase air bleed rate from compressor at low-power operation to increase combustor fuel-air ratio.
Future engines	
t7 - Variable-geometry combustion chamber	Use of variable airflow distribution to provide independent control of combustion zone fuel-air ratio.
t8 - Staged injection combustor	Use of advanced combustor design concept involving a series of combustion zones with independently controlled fuel injection in each zone.

principle, applicable to existing engines by retrofitting of new or modified parts, and to engines currently in production. Two methods are considered to be applicable only to future engines of new design, since the modifications required are too extensive to be applied to engines for which development has been completed.

The first control method consists of simple modifications of the combustor and fuel nozzles to reduce all emission rates to the best levels currently attainable within each engine class. The degree of control attainable depends upon the performance of specific engines compared with those engines in the same class demonstrating the lowest emission rates. In general, this control method requires emission quality control (emission reduction to levels demonstrated by other engines of that model). Additionally, for certain high-emission engine models, it means emission reduction to the level of other engines of the same class. Each of the other control methods is more specifically directed at one or two pollutant classes.

Reductions in emissions achievable through the use of a control method vary with the pollutant considered, the engine class, and the engine operating mode. Estimates of the effectiveness of each control method have been made for all combinations of these factors and are presented in Tables 21 and 22. The estimation of emission control effectiveness for turbine engines is based upon reductions attainable from "lowest current emission rates." These rates are defined as those attainable through control method t1 (table 19), minor combustion chamber redesign.

It is predicted that all engines in each class could be modified to achieve these "best rates." The values of these rates are listed in Table 21. These "best rates" are not the lowest rates indicated for each engine class, but are rates near the low end of those emission rates that appear to be realistically attainable. The use of the "best rate" basis is necessary to allow effectiveness estimates for each engine class. Because of the wide variations in actual emission rates of turbine engines, an effectiveness analysis based on average rates would be less significant. Table 22 indicates the effectiveness of control methods t2 through t8. Some estimates are based upon demonstrated performance. Most, however, are not based on direct experience with these control methods on aircraft engines. Therefore, estimates of effectiveness are based largely on theoretical analyses of engine performance under the operating conditions associated with the control methods. The bases for these estimates are summarized in Table 23.

Table 21. EFFECTIVENESS OF t1 - MINOR COMBUSTION CHAMBER REDESIGN[a] - ON REDUCTION OF EMISSIONS FROM TURBINE ENGINES

(Emission rates in lb/1000 lb of fuel)

Engine class	Pollutant	Mode		
		Idle/taxi	Approach	Takeoff
T1	CO	25	5	2
T1	THC	10	1	0.2
T1	NO_x	3	7	11
T1	DP	0.2	0.5	0.5
T2	CO	45	6	1
T2	THC	10	1	0.1
T2	NO_x	2	6	12
T2	DP	0.2	0.5	0.5
T3	CO	50	3	0.5
T3	THC	10	1	0.1
T3	NO_x	3	10	40
T3	DP	0.1	0.1	0.1

[a] Minor combustor redesign is assumed to reduce the smoke to invisible or "smokeless" levels for all engine classes.

Table 22

Effectiveness of Engine Modification in Control of Emissions from Turbine Engines, by Operating Mode[a]

Control method	Engine class	Pollutant	Mode		
			Idle/taxi	Approach	Takeoff
t2[b]	T1	DP	0.5	0.5	0.5
t2	T1	NO_x	NC[c]	NC	0.5
t2	T2	DP	0.5	0.5	0.5
t2	T3	NO_x	NC	NC	0.5
t3	T1	THC	NC	NC	0[d]
t3	T2	THC	NC	NC	0[d]
t3	T3	THC	NC	NC	0[d]
t4	T1	CO	0.25	NC	NC
t4	T1	THC	0.25	NC	NC
t4	T2	CO	0.25	NC	NC
t4	T2	THC	0.25	NC	NC
t4	T3	CO	0.25	NC	NC
t4	T3	THC	0.25	NC	NC
t5	T1	NO_x	NC	NC	0.1
t5	T2	NO_x	NC	NC	0.1
t5	T3	NO_x	NC	NC	0.1
t6	T1	CO	0.5	NC	NC
t6	T1	THC	0.5	NC	NC
t6	T2	CO	0.5	NC	NC
t6	T2	THC	0.5	NC	NC
t6	T3	CO	0.5	NC	NC
t6	T3	THC	0.5	NC	NC
t7 or t8	T1	CO	0.1	NC	NC
t7 or t8	T1	THC	0.1	NC	NC
t7 or t8	T1	NO_x	NC	NC	0.75
t7 or t8	T1	DP	0.5	0.5	0.5
t7 or t8	T2	CO	0.1	NC	NC
t7 or t8	T2	THC	0.1	NC	NC
t7 or t8	T2	NO_x	NC	NC	0.75
t7 or t8	T2	DP	0.5	0.5	0.5
t7 or t8	T3	CO	0.1	NC	NC
t7 or t8	T3	THC	0.1	NC	NC
t7 or t8	T3	NO_x	NC	NC	0.75
t7 or t8	T3	DP	0.5	0.5	0.5

[a] Emission rate is fraction of best current rate assumed to be attainable through minor combustion chamber redesign and with control method cited

[b] t2 = Major combustion chamber redesign
t3 = Fuel drainage control
t4 = Divided fuel supply system
t5 = Water injection
t6 = Modify compressor air bleed rate
t7 = Variable-geometry combustion chamber
t8 = Staged injection combustor

[c] NC indicates no change

[d] Refers to raw fuel drainage only

Table 23

Bases for Control Method Effectiveness Estimates for Turbine Engines

Control method	Rationale
t1 - Minor combustion chamber redesign	The assumption is made that emission rates for all engines within a given class can be reduced to common, optimum levels (on a lb/1000 lb fuel basis) by minor combustor modifications. These optimum emission rates are based on the best performance reported for each engine class, excluding extreme data points.
t2 - Major combustion chamber redesign	Estimates are based on reports of carbureting fuel injector performance and reduction of smoke emission. Concept is incorporated in some Class T3 engines. Estimates are based on assumption that best emission rate for Class T1 and T2 engines is at an exhaust visibility threshold at maximum power. Carburetion appears to reduce smoke level, and presumably particulate emissions, to approximately half that level. Additionally, premixing of air and fuel can be used to give substantial NO_x reduction by decreasing residence time in the combustor.
t3 - Fuel drainage control	Estimate is based on the assumption that fuel drainage can be completely eliminated by collecting drained fuel and returning to fuel tank.
t4 - Divided fuel supply system	Control method results in combustion zone fuel-air ratio similar to that at approach condition. Reduction in CO and THC from idle to approach is approximately 90 percent in Class T1 and T2 engines and 90 percent in Class T3 engines. Effectiveness is reduced by one order because combustor is not operating at "well-designed" condition.
t5 - Water injection	Water injection is assumed only at takeoff at a rate up to twice the fuel rate. Water injection into compressor or diffuser is assumed to be by system similar to those in current use. Effectiveness based upon published results with steam injection.[28] Water injection assumed to be of equal effectiveness when injected upstream of combustor.
t6 - Modify compressor air	Assumptions are (1) fraction of air that can be bled is small so that engine operating point is nearly unchanged, (2) combustor f/a varies inversely with air bleed rate, and (3) CO and THC emissions at idle vary as the (air mass flow rate)^3 and inversely as $(f/a)^3$. This relationship is based upon data from Reference 14. If maximum air bleed rate is 20 percent, CO and THC emission rates are reduced by 50 percent.
t7 - Variable-geometry combustion chamber	Combustor primary zone is assumed to operate at a constant f/a equal to normal f/a at approach power condition (primary equivalence ratio = 0.6). CO and THC emissions at idle are reduced to levels corresponding to approach power, or by 90 percent for Classes T1, T2, and T3. This incorporates design characteristics that provide a good mixture in the combustion zone. This feature and constant f/a operation combine to reduce NO_x emissions at full power by 75 percent[26] and particulate emissions by 50 percent at all power levels as in t2.
t8 - Staged injection combustor	

Emission-control effectiveness is indicated in Tables 21, 22, and 23 for each control method and for each pollutant for which a significant degree of control expected. Pollutants for which little or no control expected are not listed. Effectiveness is indicated separately for each engine class. No specific estimates have been made for control of reactive hydrocarbons, odor, or aldehydes because control methods applicable to these emissions are not yet identified. Reductions in these emissions are expected along with reductions in THC emissions. Any of the modifications defined for existing turbine engines (t1 through t6) could be combined to achieve increased emission control effectiveness; exceptions are modifications t4 and t6, which are mutually exclusive.

Piston Engines - The control methods considered feasible for aircraft piston engines are listed with brief descriptions in Table 24. These methods include most of the approaches that have been developed for automotive engines for control of carbon monoxide and total hydrocarbon. Methods for controlling nitrogen oxide (NOx) emissions are not included because the fuel-rich operating conditions of aircraft piston engines result in low NOx emission rates. Piston engine emission characteristics are included in Figure 11. As this figure indicates, fuel-air ratio has a significant effect on aircraft piston engine emissions. Plans for changes in engine operating conditions to reduce CO and THC emissions must also consider NOx to prevent significant increases in emissions of this pollutant.

Table 24 lists nine piston-engine control methods, including the use of direct-flame afterburners and water injection, methods that are not being considered currently for automotive engines. Afterburners might be used to advantage in this application because they can utilize the high-velocity airflow around the aircraft. Although aircraft piston engines and automobile engines are fundamentally similar, their applications are significantly different, with different requirements. Reliability is of primary importance in aircraft piston engine applications and therefore is given paramount consideration in identifying applicable control methods. The piston-engine emission-control methods were identified and evaluated through reviews of published investigations. Of the methods identified, all are considered applicable to existing engines except those that would require redesign of the basic engine or its control systems.

Effectiveness estimates for piston engines are based on reductions of current uncontrolled rates listed in Table 25.

Table 24

Engine Modifications for Emission Control for Existing and Future Piston Engines

Control method	Modification
Existing engines	
p1 - Fuel-air ratio control	Limiting rich fuel-air ratios to only those necessary for operational reliability.
p2 - Simple air injection	Air injected at controlled rate into each engine exhaust port.
p3 - Thermal reactors	Air injection thermal reactor installed in place of, or downstream of, exhaust manifold.
p4 - Catalytic reactors for HC and CO control	Air injection catalytic reactor installed in exhaust system. Operation with lead-free or low-lead fuel required.
p5 - Direct-flame afterburner	Thermal reactor with injection of air and additional fuel installed in exhaust system.
p6 - Water injection	Water injected into intake manifold with simultaneous reduction in fuel rate to provide for cooler engine operation at leaner fuel-air ratios.
p7 - Positive crankcase ventilation	Current PCV system used with automotive engines applied to aircraft engines. Effective only in combination with one of preceding control methods.
p8 - Evaporative emission controls	A group of control methods used singly or in combination to reduce evaporative losses from the fuel system. Control methods commonly include charcoal absorbers and vapor traps in combination with relatively complex valving and fuel flow systems.
Future engines	
p9 - Engine redesign	Coordinated redesign of combustion chamber geometry, compression ratio, fuel distribution system, spark and valve timing, fuel-air ratio, and cylinder wall temperature to minimize emissions while maintaining operational reliability.

FIGURE 11

PISTON ENGINE EMISSION CHARACTERISTICS

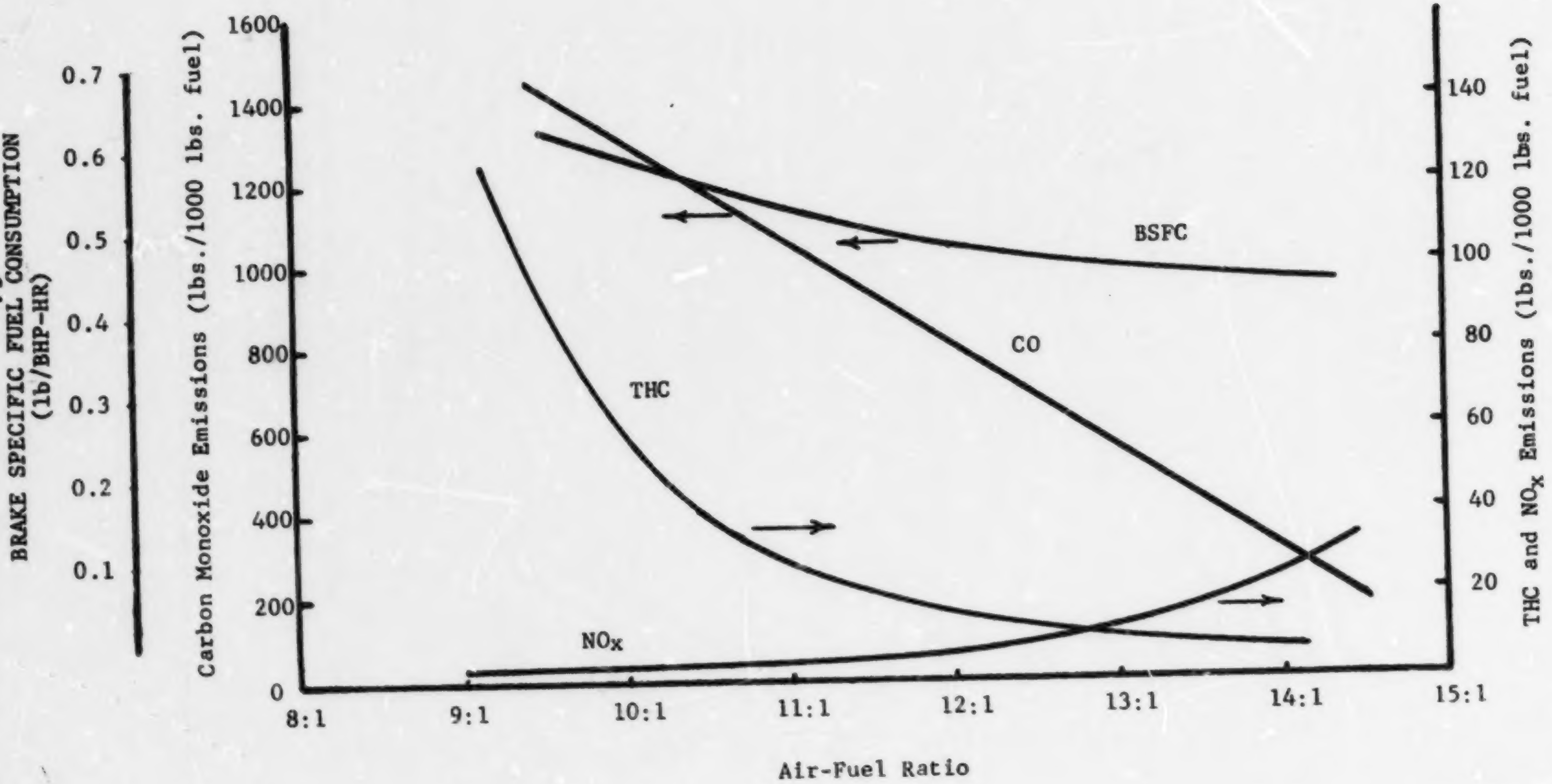


TABLE 25

CURRENT UNCONTROLLED EMISSION RATES FOR PISTON ENGINES[29]

(lb/1000 lb of fuel)

Pollutant	Idle	Taxi	Approach	Takeoff
CO	896	882	918	849
THC[a]	48	76	80	18
NO_x (as NO_2)	7	4	4	6

[a] Total hydrocarbon (THC) emission rates have been increased by 50% to account for crankcase blow-by emissions. Evaporative emissions are not included in these rates.

TABLE 26

EFFECTIVENESS OF ENGINE MODIFICATIONS IN CONTROL OF EMISSIONS FROM PISTON ENGINES BY POLLUTANT[a]

Control Method	Controlled Emission Rate CO	Controlled Emission Rate THC[b]
P1 Fuel-air ratio control	0.5	0.5
P2 - Simple air injection	0.1	0.5
P3 - Thermal reactor	0.1	0.25
P4 - Catalytic reactor (requires lead-free fuel)	0.1	0.25
P5 - Direct-flame afterburner	0.1	0.1
P6 - Water injection	0.1	0.25
P7 - Positive crankcase ventilation (PCV)	NC	d
P8 - Evaporative emission control	NC	e
P9 - Engine redesign	0.1	0.5

[a] Emission rate is fraction of uncontrolled emission rate after installation of control method and applies to all operating modes.

[b] Exhaust HC only.

[c] NC indicates no change.

[d] PCV would eliminate blow-by emissions when used in combination with pl, p2, p3, p4, p5, or p8. Blow-by THC emission estimated to be equal to 30% of uncontrolled exhaust emission.

[e] Evaporative controls would reduce THC emissions due to evaporation from fuel supply. Magnutude of uncontrolled emissions is inknown.

Since emission rates from piston engines do not vary as widely as those from turbine engines, control effectiveness can be based on average rates for existing engines. The effectiveness estimates shown in Table 26 are based in most cases on the application of individual control methods without other engine changes. Method p7 (PCV) is an exception; it is considered to be most effective in combination with method p1, p2, p3, p4, p5, p6, or p9.

Piston-engine modifications p2 through p6 are designed to serve the same function and, thus, are mutually exclusive. All of the others could be combined with any of the modifications p2 through p6 to achieve increased emission-control effectiveness.

Cost and Time Requirements for Control-Method Development and Implementation

Existing Engines - Estimates of the cost and time requirements of applying each control method applicable to existing engines are preliminary and are intended to indicate the magnitude of costs and time involved in controlling emissions from all civil aircraft. Cost and time requirements are estimated separately for control-method development and implementation. Development includes all effort required from initial stages through certification of the control method for a specific engine class and tooling for production. Implementation includes initial installation of the control method on all engines of a given class and costs associated with additional effort or materials required for the control method throughout the remaining service life of the engines. These estimates are based on a turbine engine life of 10 years with engine overhauls every 5,000 hours or 2 1/2 years and a piston engine life of 10 years with engine overhauls every 5,000 hours or 5 years. Operating costs for water injection are based upon experience with the water injection system on the Boeing 747 aircraft.

Because few of the control methods have been developed for or applied to aircraft engines, and because many factors affect total implementation costs, many uncertainties are involved in the estimates. Estimates of development costs and time requirements are based on the previous experience of aircraft engine manufacturers in similar modifications. Estimates of implementation costs are considered to be less certain than development costs. The cost and service life of a modified engine component is difficult to predict accurately. Yet these factors strongly affect the cumulative costs of operating and maintaining the modified engine. Because implementation costs could be far greater than development costs for some control methods, the estimates of implementation costs are only indicative of cost penalties that might be involved with control-method implementation.

Three potential levels of aircraft emission control entail three distinct associated cost levels: (1) retrofitting in-use engines, (2) modifying present production designs to incorporate emission control technology in new engines of models presently being produced, and (3) incorporating emission control technology into new engine designs during the design phases of a new engine model.

Costs are highest for retrofitting in-use engines, are significantly lower for modifying existing designs in new production engines and are lowest for incorporating emission technology during engine design. Table 27 presents estimates of the development time, development costs, and implementation costs for application of the control methods that could be retrofitted on the current population of all civil engines.

The development time requirements listed in Table 27 are the periods required to reach the point where installation of the control methods in existing engines could begin. The application of controls in all existing engines would require an additional time period that depends primarily on the availability of engine maintenance facilities. The time for implementation is estimated to be 2 1/2 years for turbine engines and 5 years for piston engines. These time estimates allow implementation of the emission control method during normal maintenance procedures, minimizing cost. Table 28 presents costs by category: air carrier, general aviation, and civil aviation. These tables represent cost to retrofit the various control methods to the current population of aircraft.

From another perspective, implementation costs may be expressed as fractions of total engine costs. For a typical class T2 (turbine) engine, the cost of installing and maintaining control systems ranges from $300 to $69,900, assuming a 10-year engine life. Based on a total engine cost of $250,000, these control-method implementation costs represent 0.1 to 25 percent of the total engine cost. For a typical piston engine, estimated control-method implementation costs range from $100 to $4,000, also based upon a 10-year engine life. For a total engine cost of

Table 27

Time and Costs for Modification of Current
Civil Aviation[a] Engines

Control method	Development time, years	Development cost, 10^6 dollars	Implementation cost, 10^6 dollars
Turbine engines			
Minor combustion chamber redesign	2.5 to 5	37	383
Major combustion chamber redesign	2.5 to 7.5	74	665
Fuel drainage control	1 to 2.5	1.5	5.4
Divided fuel supply	5 to 7.5	84	102
Water injection	2.5 to 4	25	175
Compressor air bleed	4 to 6.5	90	58
Piston engines			
Simple air injection	1.5 to 3	9	165
Thermal reactor	3 to 6	25	424
Catalytic reactor	2.5 to 5	22	535
Direct-flame afterburner	3 to 6	25	424
Water injection	1.5 to 3	9	400
Positive crankcase ventilation	2 to 4	4	94
Evaporative emission control	1.5 to 2.5	4	269

[a] "Civil aviation" includes air carrier and general aviation engines

Table 28

Cost Results for Turbine Engine Population
by Separate Use Categories

Engine class	Control method	Cost scaling factor	Development cost per engine family, 10^6 dollars	Implementation cost per engine, 10^3 dollars	Total cost, 10^6 dollars		
					Air carrier	General aviation	Civil aviation[a]
T1	t1	0.35	0.90	12.4	19.2	90.5	109.7
T1	t2	0.35	1.80	21.3	34.5	159.3	193.8
T1	t3	--	0.05	0.1	0.4	1.0	1.4
T1	t4	0.35	1.80	3.7	14.9	51.5	66.4
T1	t5	0.35	0.62	5.5	9.8	43.6	53.4
T1	t6	0.35	2.20	2.1	15.5	48.1	63.6
T2	t1	1.00	0.90	35.5	243.0	17.8	259.8
T2	t2	1.00	1.80	69.9	418.0	31.0	449.6
T2	t3	--	0.05	0.3	2.0	--	2.0
T2	t4	1.00	1.80	10.5	87.0	8.3	95.3
T2	t5	1.00	0.62	15.6	108.7	8.2	116.9
T2	t6	1.00	2.20	6.0	61.5	7.1	68.6
T3	t1	1.64	0.90	58.3	50.0	--	50.0
T3	t2	1.64	1.80	100.0	95.0	--	95.0
T3	t3	1.64	0.05	0.6	2.0	--	2.0
T3	t4	1.64	1.80	17.2	13.7	--	13.7
T3	t5	1.64	0.62	25.6	29.5	--	29.5
T3	t6	1.64	2.20	9.9	16.0	--	16.0

[a] "Civil aviation" includes air carrier and general aviation engines

$6,000, these implementation costs represent 2 to 65 percent of the total.

Retrofit cost and time estimates for turbine engines were developed by using the application of low-smoke combustors to the JT8D engine class as a reference for cases in which no direct experience was available. Cost and time requirements for this modification, which is considered a minor combustor redesign for a class T2 engine, were estimated in detail in 1969.[27] Requirements for other control methods were determined essentially by proportioning the cost and time expenditures according to the complexity of the method, with respect to the reference case. Requirements for other engine classes were determined by using appropriate scaling factors and by again using the JT8D modifications as reference. Time and cost estimates for piston engines are based largely on experience to date with emission controls for automobile engines. Significant differences, such as certification and safety requirements and production levels, were considered in scaling the costs from the experience with automobiles.

Costs of emission control technology are substantially lower when applied to new engines only. These costs are less than one-half the retrofit costs on a per-engine basis. These estimates cannot be totalled as were the retrofit estimates because of uncertainty concerning the number of engines that would be affected.

Future Engines - Cost estimates have been developed also for incorporation of emission controls in future engines, that is, engines that have not yet been developed. These estimates are defined only as fractions of total engine cost, since no reasonable basis is available for estimating the numbers of engines that would be affected.

Emission control in turbine engines that is attained through the use of advanced combustor-design concepts is estimated to represent an increase in total engine cost of 3 to 4 percent. Emission control in piston engines that is achieved by engine-design modifications would not necessarily result in any significant increase in engine cost. If greater control of emissions is required than can be achieved by engine design modifications, however, one or more of the control methods applicable to existing engines will be necessary. The costs of these control methods, which involve the addition of auxiliary devices such as thermal reactors, will be significant, probably in the range of 5 to 10 percent of total engine cost.

These estimates represent the increased costs of new engines with emission controls installed. Additional continuing costs may accrue for maintenance of the controls. These maintenance costs will be considerably less than those entailed in modifications of existing engines.

EMISSION CONTROL BY MODIFICATION OF GROUND OPERATIONS

Definition of Ground Operations

The cycle of operations performed by an aircraft during its arrival at and departure from an airport can be defined quite precisely because most of these operations are prescribed by airport or aircraft operating procedures. Characteristic operating or LTO (landing-takeoff) cycles have been defined for various classes of aircraft for purposes of estimating pollutant emissions.

The LTO cycle can be separated logically into flight and ground operations. Flight operations include the approach and climb-out modes as well as landing and takeoff, even though the latter occur partially on the ground. Ground operations include the taxi and idle modes of the cycle. This separation is logical for two reasons. First, flight operations as defined here are those that cannot readily be modified to reduce pollutant emissions. Second, flight operations are conducted almost entirely with aircraft engines at full or part power; under these conditions, pollutant emission rates are quite different from those at the low power levels characteristic of ground operations. Aircraft ground operations contribute substantially to the concentrations of CO and THC at air carrier airports because of the relatively high emission rates of these pollutants at low engine power levels, and because ground operations are largely confined to limited areas within the airport boundaries.

Emission Control Methods

Six methods offer some degree of control of CO and THC emissions at air carrier airports by modification of turbine-aircraft ground-operation procedures.

(1) Increase engine speed during idle and taxi operations.

(2) Increase engine speed and reduce number of engines operating during idle and taxi.

(3) Reduce idle operating time by controlling departure times from gates.

(4) Reduce taxi operating time by transporting passengers to aircraft.

(5) Reduce taxi operating time by towing aircraft between runway and gate.

(6) Reduce operating time of aircraft auxiliary power supply by providing ground-based power supply.

The first two methods reduce emissions by requiring that engines be operated at more efficient power settings than those in current practice (Figure 12); the next four methods reduce emissions by reducing operating time of either main or auxiliary engines. The effectiveness of these methods in reducing emissions varies considerably. Table 29 summarizes the reductions in CO and THC emissions that would result at Los Angeles International Airport from the six suggested ground-operation changes. Tables developed for other major air carrier airports show emission reductions of the same magnitude.

The control methods listed, with the possible exception of number 3, are not applicable to small, piston-engine aircraft, and, therefore, do not seem to offer means for controlling emissions at general aviation airports. Periods of delay at take-off are significant at some general aviation airports; however, aircraft ground traffic at general aviation airports may not be sufficiently controlled to allow an effective system of controlled gate departures or engine start-ups to reduce periods of delay.

Implementation Cost and Time Requirements

The cost and time requirements of the control methods involving ground operation modifications have been estimated for Los Angeles International. Table 30 presents summary of the estimates. Implementation of these methods at other airports would involve costs of the same magnitude. Specific costs, however, would vary with airport activity level and the present availability of auxiliary equipment. FAA and the airlines have estimated savings for control method 2, and their estimates are within 20% of the estimate in Table 30.

Tables 29 and 30 indicate that alternative 2 is a most attractive means of reducing turbine aircraft emissions providing that operational and safety requirements can be met.

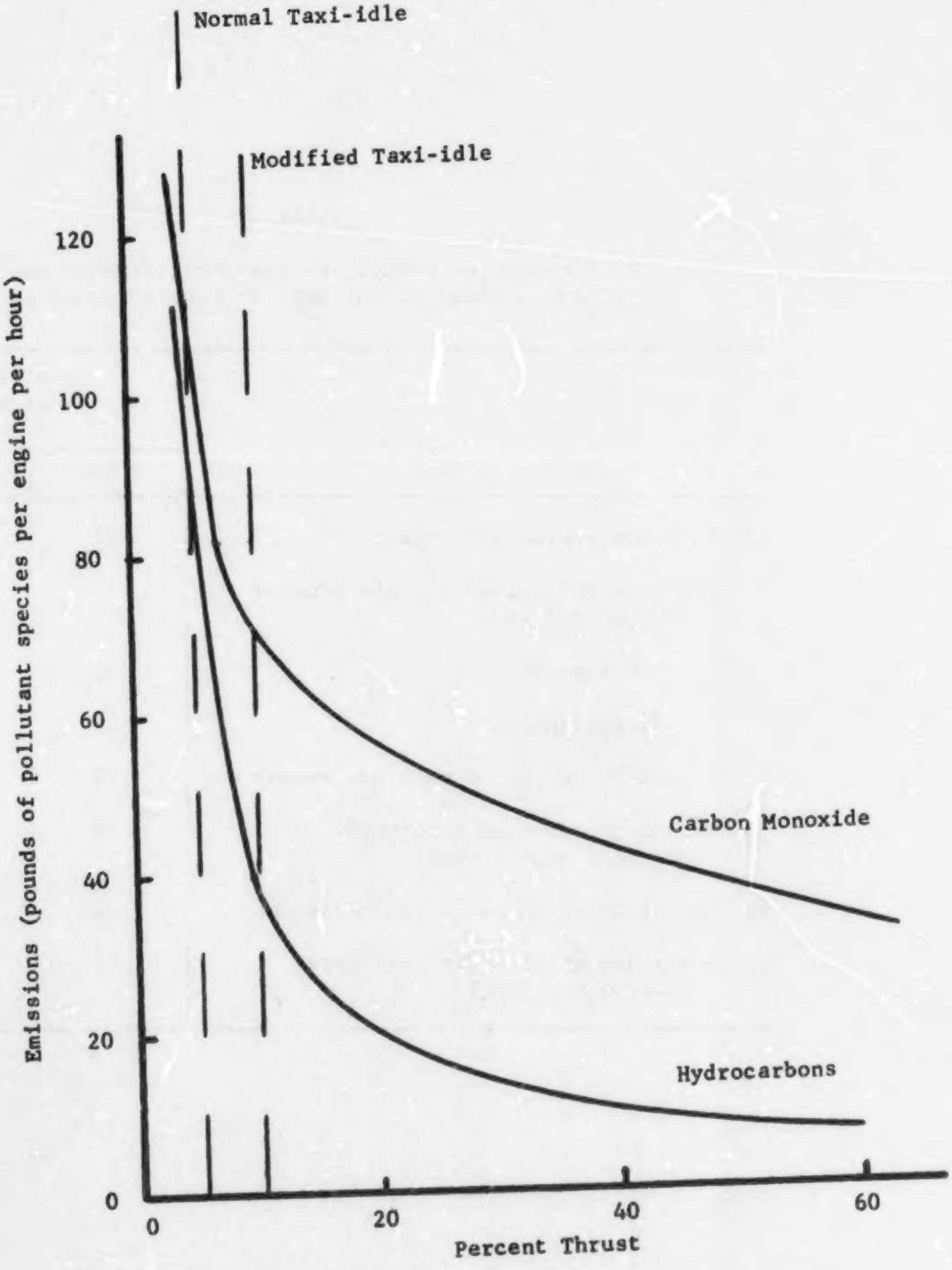


FIGURE 12

HYDROCARBON AND CARBON MONOXIDE EMISSIONS
FROM A TYPICAL AIRCRAFT TURBINE ENGINE (JT3D)

Table 29

Comparative Reductions Resulting from Control Methods Applied at Los Angeles International Airport

Control method	Resultant emissions, % of uncontrolled emissions	
	CO	Hydrocarbons
1. Increase engine idle speed	71	93
2. Increase idle speed and use minimal engines for taxi		
Two engines	53	66
Single engine	39	51
3. Eliminate delays at gate and runway	90	91
4. Transport passengers between terminal and aircraft	98	97
5. Tow aircraft to avoid taxi emissions	34	42
6. Avoid use of aircraft auxiliary power units (APU)	96	98.5

Table 30

Costs and Time for Operations Changes
at Los Angeles International Airport

Control method	Time, years	Initial cost, 10^6 dollars	Annual operating cost change,[a] 10^6 dollars
1. Increase engine speed	0	0	8.5
2. Increase speed, reduce number	0.3	0	-0.7
3. Control gate departure	5	15	-0.4
4. Transport passengers	2.5	65	5.0
5. Tow aircraft	1	1.2	0.4
6. Reduce APU operation	0.5	1.3	1.5

[a] Minus sign indicates an estimated savings

COMPARATIVE EVALUATION OF EMISSION CONTROL METHODS

The engine and ground operation modifications just discussed can be compared in terms of effectiveness, cost, and implementation time. A "potential benefit factor" has been defined to allow comparison of cost/benefit of the emission control methods. The potential benefit factor (PBF) is the net emission reduction resulting from a particular control strategy, averaged over the next 20 years, divided by the cost.

$$PBF = \frac{FYE \times CE \times ECF}{CP}$$

where FYE is the fraction of the next 20 years that the control method is effective; CE is the control method effectiveness (the percentage reduction of a particulate pollutant); ECF is the emission contribution fraction (percentage of total aircraft emissions at relevant airports contributed by engines affected by this control strategy); and CP is the cost of the control strategy for the pollutant considered. Emissions at major carrier airports were used to determine effectiveness of turbine engine control methods and those at general aviation airports to determine effectiveness of piston engine emission control methods.

The potential benefit factor is a measure of the cost-effectiveness of each control strategy. Potential benefit factors (Table 31) have been calculated for the control strategies previously described as applied to (1) retrofitting in-use aircraft, (2) modifying new engines of present models, and (3) incorporating control methods in new engine designs. The higher numbers represent the most cost-effective strategies for emission reduction.

The potential benefit factors in Table 31 are a composite for all turbine and piston engines. Although these factors indicate the relative merits of the control methods, the factor for an individual engine classification may be significantly different. For example, retrofit of water injection for class T3 shows a potential benefit factor of 4.2, whereas the average for all turbine engines is only 1.4. Additionally, while some control strategies show a high potential benefit number, other strategies must also be used to achieve significant emission reductions. For example, fuel venting represents from 4 to 20% of total hydrocarbon emissions, dependent upon airport considered. Consequently, to achieve substantial reduction of hydrocarbon emissions a less attractive control method is necessary in addition to eliminating fuel venting.

Table 31

Comparison of Emission Control Methods

Control Method	Potential Benefit Factor		
	HC & CO	NO_x	Smoke
Turbine Engines			
A. Retrofit-Engine Modifications			
1. Minor combustion chamber redesign	0.37	0.37	0.37
(APU)	(2.5)		
2. Major combustion chamber redesign	0.3	1.1	1.1
(T3 and APU)		(6.6)	
(T2 only)			(5.0)
3. Fuel drainage control	10	--	--
(T2 and T3 only)	(20)		
4. Divided fuel supply	1.5	--	--
5. Water injection	--	1.4	--
(T3 only)		(4.2)	
6. Compressor air bleed	1.3	--	--
B. New Production Engine Modification			
1. Minor combustion chamber redesign	5.0	5.0	5.0
2. Major combustion chamber redesign	4.6	4.6	4.6
3. Fuel drainage control	30	--	--
4. Divided fuel supply	5.0	--	--
5. Water injection	--	1.4	--
(T3 only)		(4.2)	
6. Compressor air bleed	4.0	--	--
C. Future Engine Emission Control			
1. Fuel drainage control	30	--	--
2. Divided fuel supply	15	--	--
3. Water injection	--	2.0	--
(T3 only)		(5.6)	
4. Compressor air bleed	15	--	--
5. Variable geometry combustion chamber	25	25	25
6. Staged injection combustor	25	25	25
D. Ground Operations Modification			
1. Increase engine idle speed	2.4	--	--
2. Increase speed, reduce number	10^5	--	--
3. Eliminate delays	10	--	--
4. Transport passengers	0.1	--	--
5. Tow aircraft	75	--	--
6. Reduce APU operation	1.0	--	--
Piston Engine			
A. Retrofit-Engine Modification			
1. Fuel-air ratio control	50	--	--
2. Air injection	5	--	--
3. Thermal reactor	2	--	--

Table 31 (Cont.)

Comparison of Emission Control Methods

Control Method	Potential Benefit Factor		
	HC & CO	NO_x	Smoke
4. Catalytic reactor	1.5	--	--
5. Direct-flame afterburner	1	--	--
6. Water injection	2	--	--
7. Positive crankcase ventilation	3	--	--
8. Evaporative emission control	1.5	--	--
B. New Production Engine Modifications			
1. Fuel-air ratio control	500	--	--
2. Air injection	30	--	--
3. Thermal reactor	6.6	--	--
4. Catalytic reactor	5.0	--	--
5. Direct-flame afterburner	3.3	--	--
6. Water injection	15	--	--
7. Positive crankcase ventilation	50	--	--
8. Evaporative emission control	3.0	--	--
C. Future Engines			
1. Fuel-air ratio control	500	--	--
2. Air injection	30	--	--
3. Thermal reactor	6.6	--	--
4. Catalytic reactor	5.0	--	--
5. Direct-flame afterburner	3.3	--	--
6. Water injection	15	--	--
7. Positive crankcase ventilation	50	--	--
8. Evaporative emission control	6.0	--	--
9. Engine redesign	25	--	--
D. Ground Operations Modifications			
1. Eliminate delays	10	--	--

A review of the PBF values in Table 31 support the following conclusions providing that all operational and safety requirements can be met:

(1) Modification 2 for ground operation procedures is the most cost-effective method of reducing hydrocarbon and carbon monoxide emissions from turbine engines,

(2) Incorporating emission control methods into design of new engines is the most cost-effective method of over-all aircraft emission control.

(3) Control of fuel-air ratio is the most cost-effective method of reducing hydrocarbon and carbon monoxide emissions from piston engines.

(4) Retrofits of class T3 turbines is a more cost-effective method for NOx control compared to retrofit of other turbine engine classes.

(5) Fuel drainage control has high PBF because of extremely low cost of implementation (CP) rather than high control effectiveness (CE).

Because cost-effectiveness varies significantly among engine classes and control strategies, several factors in addition to cost and effectiveness must be considered in developing emission control strategies for aircraft engines.

EMISSION MEASUREMENT TECHNOLOGY

Reliable methods for measuring the rates at which pollutants are emitted from aircraft engines are required for the support of an emission-control program. Emission measurements are required for evaluating the effectiveness of control methods, and specific measurement methods must be incorporated in emission-control standards.

The state of emission-measurement technology has been assessed to determine whether measurement techniques are sufficiently well advanced to support the development of emission-control methods and the implementation of emission standards for aircraft engines. The conclusion drawn from this assessment is that current measurement technology will meet the requirements of an emission-control program. Although measurement techniques for particulate emissions are inadequate at present, improved techniques are being developed through cooperative government-industry action.

Measurement of emission rates from an aircraft engine involves three major requirements:

(1) A test procedure specifying engine operating conditions.

(2) A sampling technique for obtaining a representative sample of exhaust gas.

(3) Analytical instrumentation for determining pollutant concentrations in the exhaust-gas sample.

Aircraft engine manufacturers, FAA, and EPA are devoting substantial effort toward meeting these requirements for measuring emissions from turbine engines.

Sampling and Test Procedures

Obtaining a representative sample of exhaust gas from an aircraft engine for analysis of emission rates is a complex and difficult procedure. Sampling emissions from turbine engines is difficult at the outset because of the jet-blast environment in which the sampling equipment must be installed. Beyond this problem, the following factors all significantly affect the composition of the exhaust sample:

(1) Engine power level.

(2) Temporal and spatial variations in exhaust composition.

(3) Sampling-line diameter, length, material, and temperature.

(4) Ambient temperature and humidity.

(5) Ambient pollutant levels.

Procedures for sampling and analyzing turbine-engine exhaust gases have been under development for several years by engine manufacturers, FAA, and EPA. More recently, the Society of Automotive Engineers Aircraft Exhaust Emission Measurement (E-31) Committee has been formed to standardize these procedures. Standardization of measurement techniques will minimize variations resulting from the factors listed above; however, the several sources of error in collecting exhaust samples and the variability of samples among different engines must be considered in the establishment of a standard emission measurement procedure.

Sampling requirements for aircraft piston engines are similar to those for automobile engines. The exhaust gases are well mixed by the time they reach the exhaust stack exit. Consequently, no factors are apparent, beyond those already recognized as affecting automobile exhaust emissions, that would cause variability in exhaust samples from aircraft piston engines. Differences in engine operation, however, must be considered in the establishment of a standard emission measurement procedure.

Emissions Measurement Instrumentation

Measuring the concentrations of most gaseous pollutants in exhaust samples from aircraft engines is generally within the capabilities of existing instruments and should remain so, even when engines are modified to reduce emission rates.

The various types of instruments that are available and in current use for aircraft emission measurement have been reviewed. Instruments that appear to be most suitable for measuring turbine-engine emissions at the present time are presented in Table 32.

Table 32

Instrumentation for Measurement of Turbine Engine Emissions

Measurement method	Pollutant class
Non-dispersive infrared (NDIR)	CO and CO_2
Heated flame ionization	THC
Chemiluminescence	NO
Chemiluminescence[a]	NO_2
SAE smokemeter (ARP1179)	Smoke
None	Particulates
Determined from fuel analysis	SO_2
3-MBTH	Aldehydes
Human odor panel	Odor

[a] The non-dispersive ultraviolet instrument (NDUV) may also prove acceptable for NO_2 measurement

APPENDIX A:
ANALYSIS OF CARBON MONOXIDE CONCENTRATION AT LOS ANGELES INTERNATIONAL AIRPORT

When continuous air quality monitoring data is available, statistical analysis may be applied to determine frequencies of occurrence of any concentration for any averaging time either by interpolation of the data or by extrapolation if the available data is limited. It has been observed that all air quality data regardless of averaging time follows a log normal distribution.[13]

The continuous carbon monoxide data taken at LAX during six months in 1970 were analyzed statistically for 1-hour and 8-hour averaging times at several sites to determine the expected frequencies when the NAAQS would be exceeded. With the use of the simple rollback technique, adjusted frequencies could be determined for changes in emissions and various control strategies for aircraft and non-aircraft emission sources. Dispersion modeling results were used to predict the degree of influence aircraft emissions have in locations beyond the boundaries of Los Angeles Airport.

The analysis focussed on the 8-hour exposure case in areas adjacent to the airport where it would be expected that people would meet the exposure time criteria either as residents or business employees. The 1-hour exposure case would apply to the terminal area itself as well as the areas considered in the 8-hour averaging time case.

Corrections were made to the available ambient data because of the recognized seasonal variation of carbon monoxide levels in the Los Angeles basin. A recent report published by the LAAPCD contained sufficient data to calculate the summer-winter correction factors for the hourly and 8-hour averaging times. The average correction factors for the basin to convert August-September data to December-January data were found to be 1.5 for the 1-hour data and 1.9 for the 8-hour case.

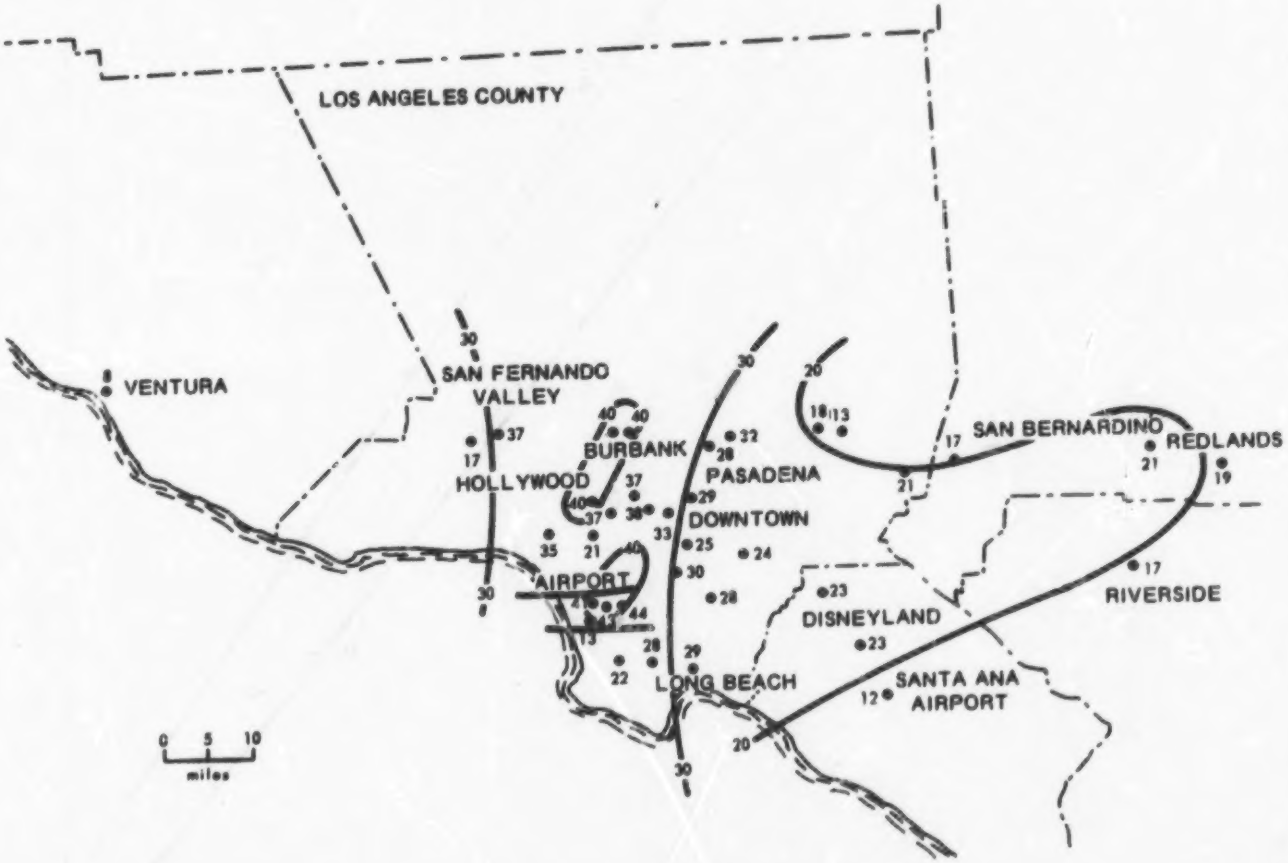
Data and statistical information on carbon monoxide analysis presented in a paper by Larsen[31] were also utilized in this phase of the analysis. The L. A. basin CO data in the Larsen paper were used to check the LAX data for consistency in terms of the frequency and range of observed carbon monoxide levels. Tabulated and plotted data in this reference indicates the air pollution hot spot represented by the Los Angeles Airport and its environs. Figure A-1, taken from the reference shows this point quite clearly. Figure 1 in the main text of this report indicates the location of the continuous ambient carbon monoxide stations. Station 209 was chosen as representative of an off airport site for the 8 and 1-hour analysis. Figure A-2 shows the plot of the raw station 209 data for the months of August and September.

It is obvious that station 209 is directly influenced by the airport only when the wind is blowing from a westerly direction. The September data were categorized into East or West influences and the results are plotted on Figure A-3. It can be seen that the composite plot is representative of both these subcategories and therefore was used for all subsequent analysis. It further demonstrates that the airport exerts the same impact on the air quality at station 209 as the non-airport area sources surrounding it. Figure 2, in the text of the report, shows the August station 209 frequency distributions for maximum 8-hour daily averages adjusted for the summer-winter correction factor. The frequency of occurrence relating to one day per quarter is assumed to be equivalent to the one day per year frequency associated with the 8-hour NAAQS because it can be assumed that the worst exposure case would occur during the winter quarter of the year. This plot has then been adjusted (Figures A-4 and A-5) for expected rollback emission reductions of non-aircraft sources in combination with various percent contributions due to aircraft sources and assumed levels of aircraft emission controls. Similar methodology was used in estimating expected 1980 CO concentrations with various aircraft contributions. These are given in the main text. Modeling results were used to determine the relating distribution and magnitude of aircraft emissions around LAX. It can be seen that the station 209 analysis is quite representative of other areas adjacent to LAX where adverse influences of aircraft operations can be expected to occur.

The same procedures were followed in plotting the adjusted September data to determine the frequency with which the standard would be expected to be exceeded for various

FIGURE A-1.

MAXIMUM ANNUAL 8-HOUR-AVERAGING-TIME CONCENTRATION OF CARBON MONOXIDE EXPECTED AT VARIOUS SITES IN THE LOS ANGELES AREA.


LOS ANGELES COUNTY
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SAN FERNANDO VALLEY
HOLLYWOOD
BURBANK
PASADENA
DOWNTOWN
AIRPORT
LONG BEACH
DISNEYLAND
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FIGURE A-2

BASELINE DATA, DAILY MAXIMUM 8-HR. AVERAGE
CO CONCENTRATIONS, STATION 209, LAX, 1970

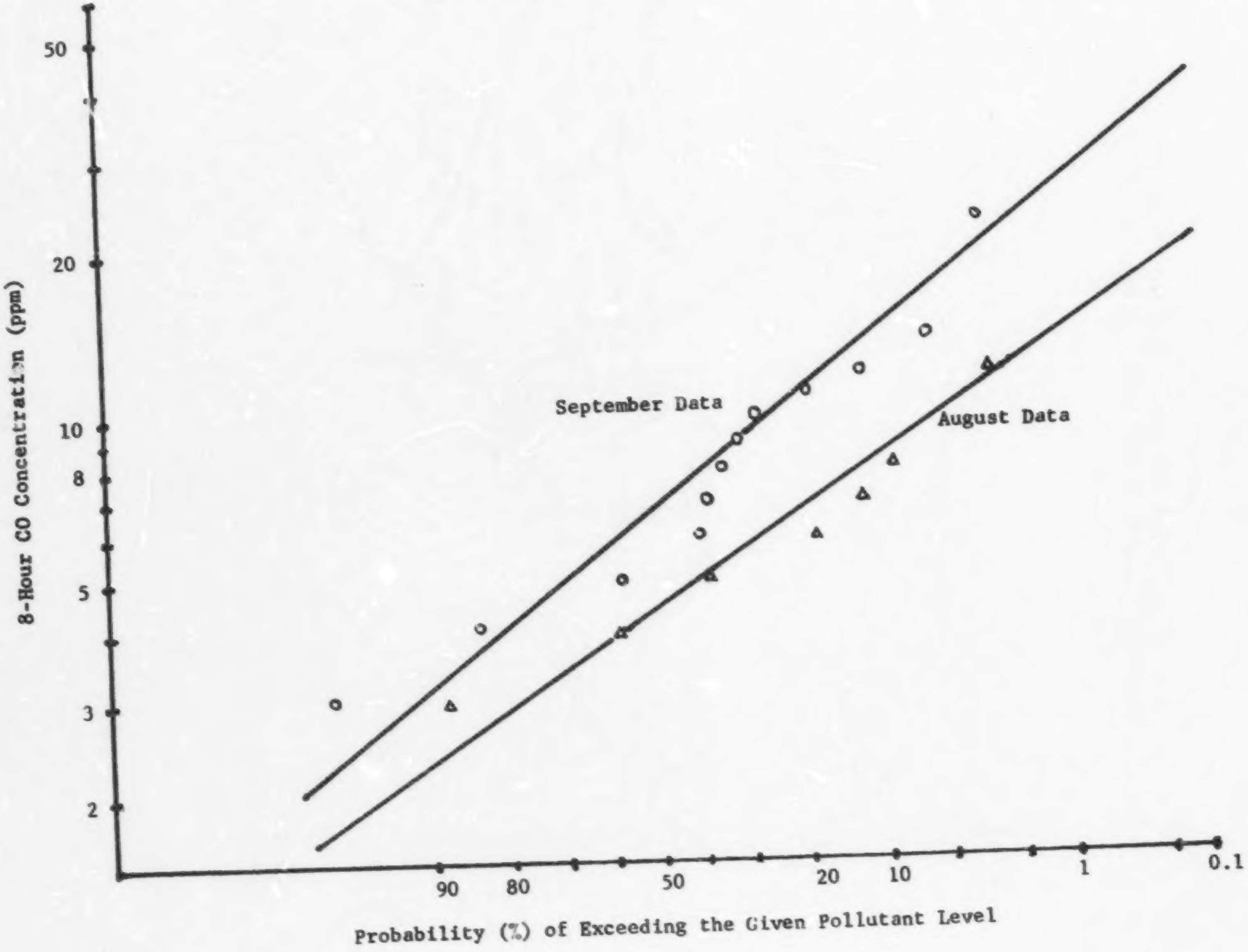


FIGURE A-3
FREQUENCY DISTRIBUTION FOR 8-HR. CO DATA, STATION 209, LAX, SEPTEMBER 1970

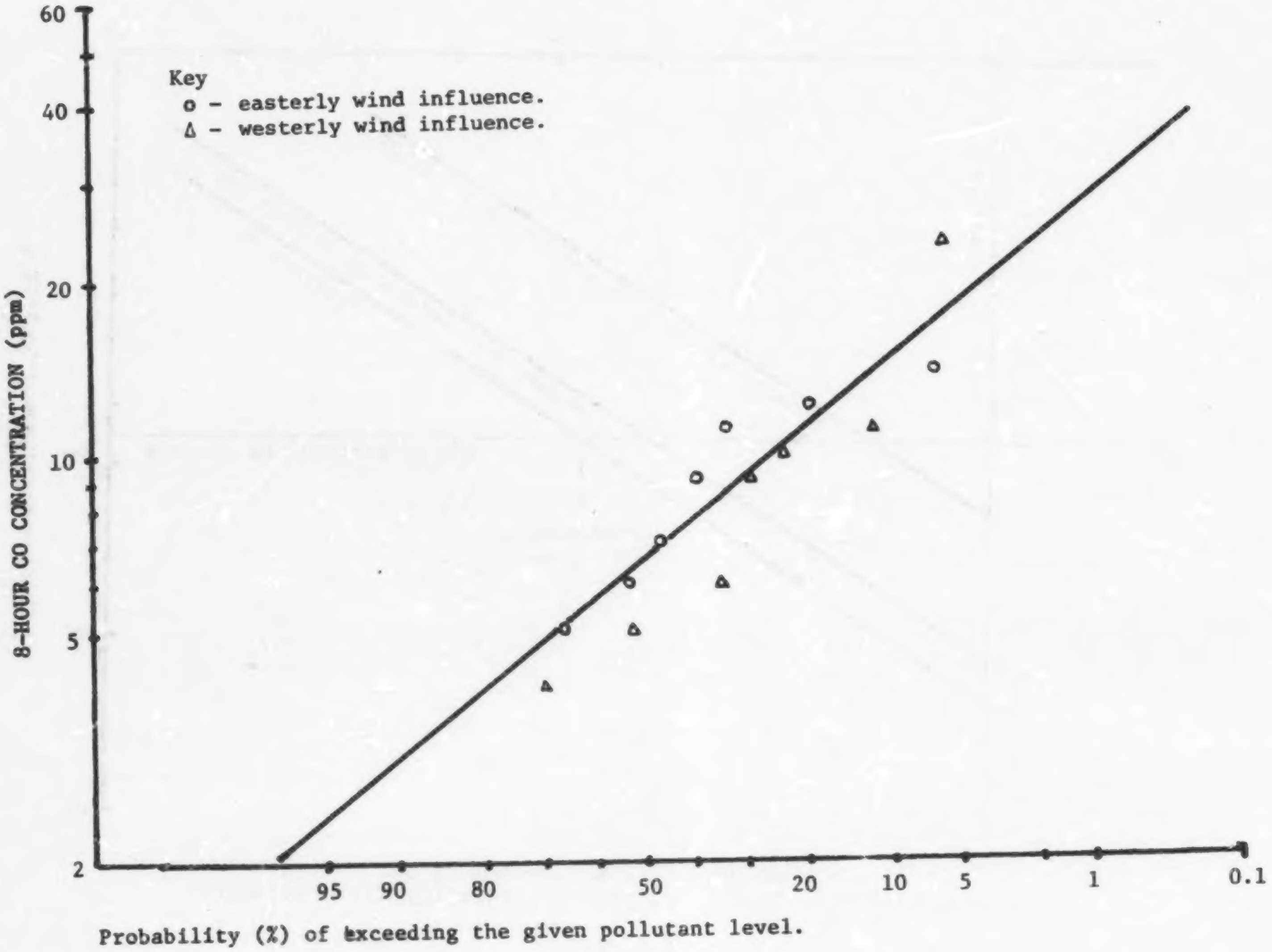


FIGURE A-4

EXPECTED CO CONCENTRATION DISTRIBUTION, WINTER, STATION 209, LAX
FOR 80 PERCENT AIRCRAFT CONTRIBUTION

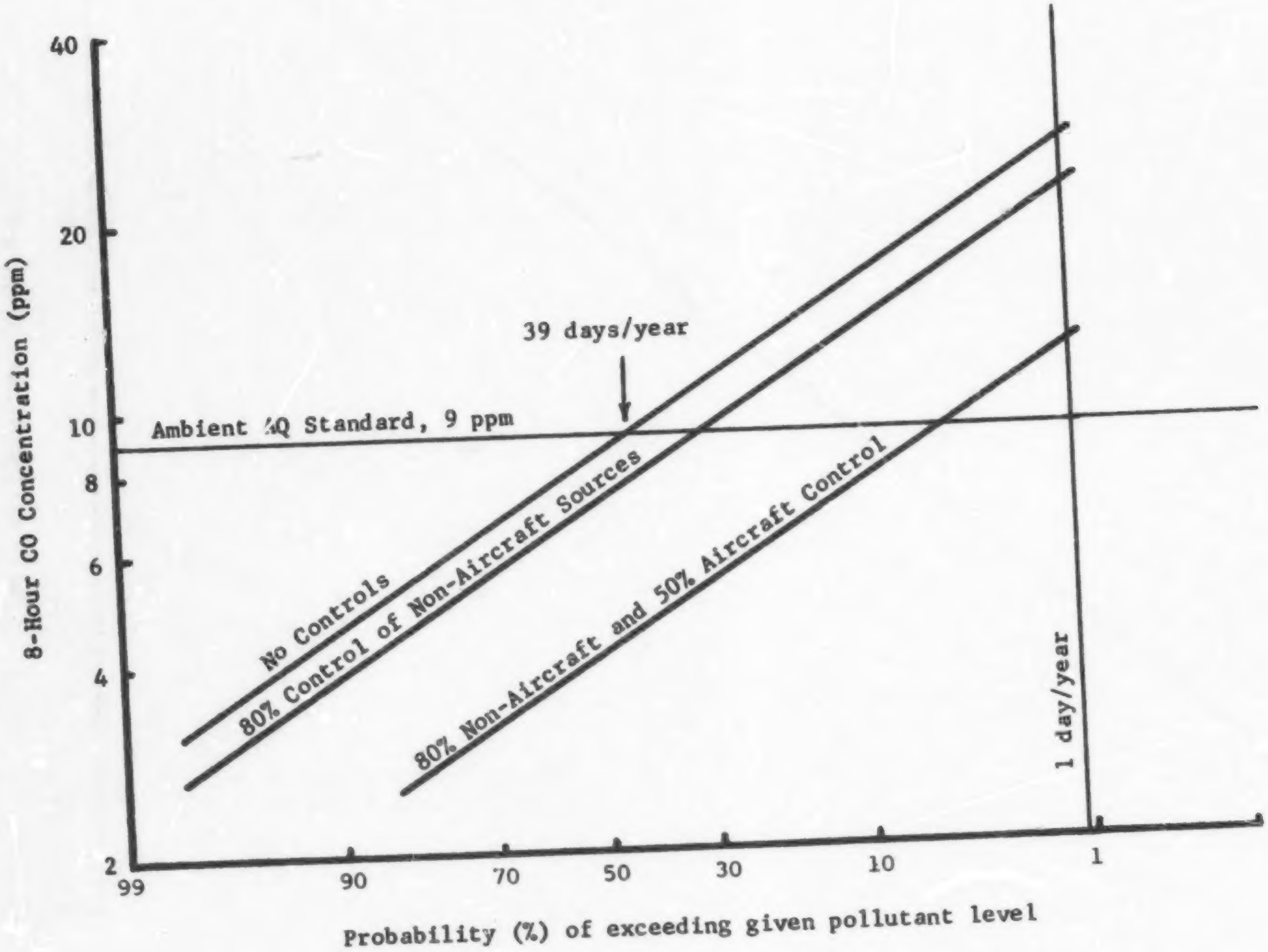
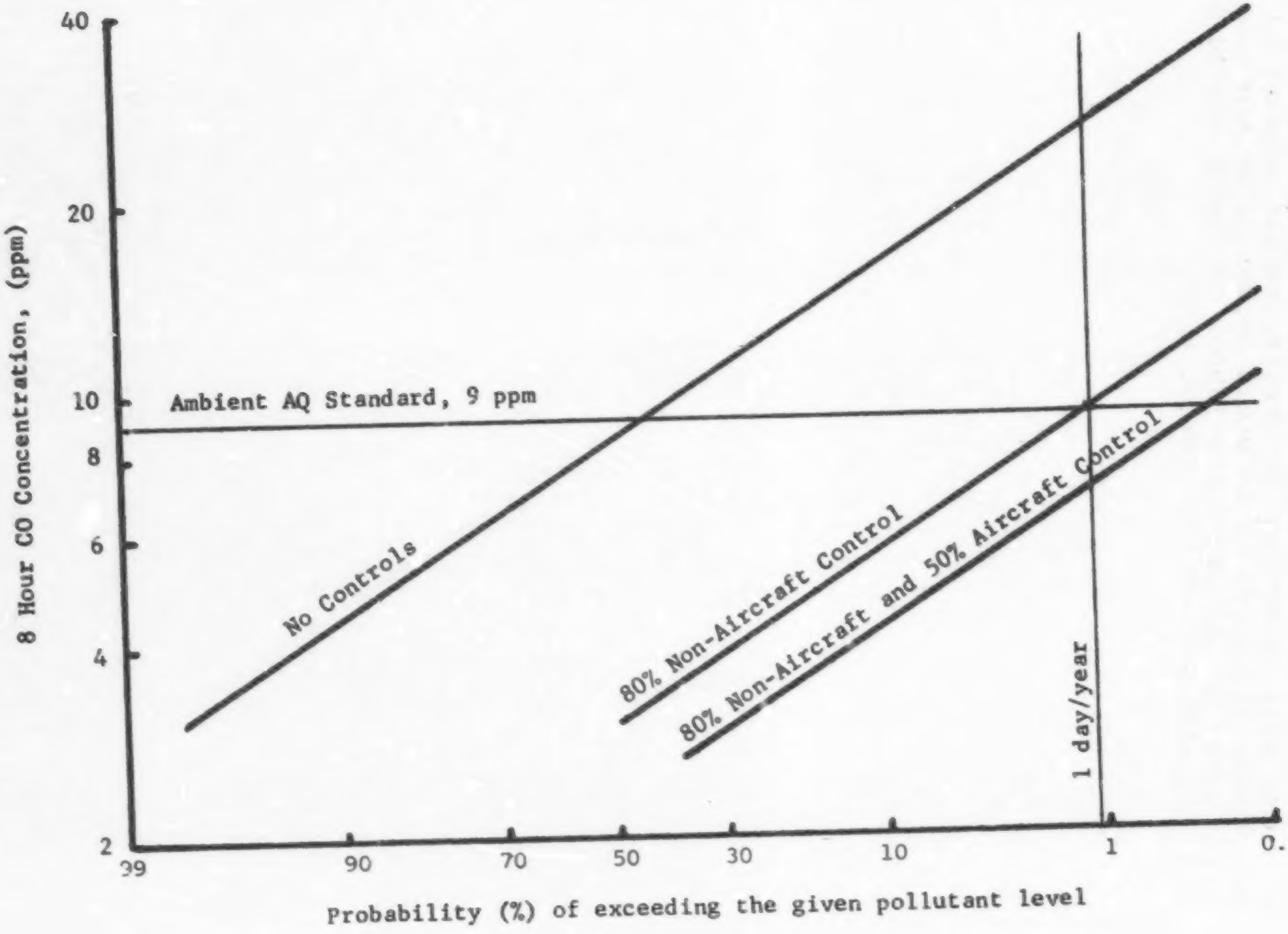


FIGURE A-

EXPECTED CO DISTRIBUTION, WINTER, STATION 209, LAX
FOR 20 PERCENT AIRCRAFT CONTRIBUTION



percent aircraft contributions. This data would represent the upper limits of the analysis.

Similar frequency analysis can be performed for the 1-hour exposure case. However, unless there is extreme variation between the slopes (or standard geometric deviations) of the 1-hour data and the 8-hour averaging time data, the 1-hour standard will be met if the strategies are imposed to meet the 8-hour standard. This would appear to be the case in those areas at LAX where the 1-hour CO levels are higher than the standard at the present time.

APPENDIX B:
DISPERSION MODELING METHODOLOGY AND ISOPLETH DERIVATION

The primary and most direct method of estimating aircraft contributions to air pollutant concentrations involved the application of frequently used dispersion modeling procedures to estimate air pollutant concentrations caused by aircraft alone and by all sources located in the airport vicinity (within a 10-kilometer radius of the airport center). Dispersion models similar to the one used in this study are specified by EPA as one means of showing that implementation plans for certain regions will be adequate to meet the ambient air quality standards. Much of the analysis of aircraft air quality impact presented in this report is based on modeling work performed, under EPA contract, by Northern Research and Engineering Corporation. A general description of the modeling procedure is presented here; a more detailed account of the modeling work and results is available in the contract report.[3]

The procedure in the modeling study involved: (1) approximating emission sources as continuous, stationary point sources of constant strength over the time period being considered, (2) modeling the dispersion of pollutants from these sources using an empirical mathematical model, and (3) estimating concentrations at specified receptor points by summing the pollutant contributions from each point source, and (4) constructing isopleths of estimated pollutant concentrations based on the estimated receptor point concentrations.

The point sources used in the modeling approximated the location and strength of emission sources at each of the four airports studied. Lines along which automobile or aircraft movement occur were represented by series of point sources. Area sources, representing airport surroundings out to a 10-kilometer radius from the airport center, were represented by circular arrangements of point sources around the airports. Altogether, 149 to 276 point sources were used for each air carrier airport, depending on the size and complexity of the airport. The number of sources was chosen to provide a reasonable approximation of emissions at the airport and in the vicinity without need for excessive computer time or computer program complexity.

The basis of the atmospheric dispersion modeling is an empirical, mathematical approximation of pollutant dispersion after emission from a point source. This approximation yields a plume whose concentration distribution is Gaussian in the vertical and crosswind direction. The distribution is dependent upon downwind distance from the source and on atmospheric stability. Eventually the upper boundary of the atmospheric mixing layer restricts vertical spread of the plume and modifies the distribution of pollutants in the vertical direction. This dispersion model should be considered as a general approximation of airport dispersion patterns; considerable model development would be required to include more detailed small-scale dispersion patterns, such as those around large buildings or near jet blasts.

In calculation of long-term concentrations, the fact that there is a distribution of meteorological conditions is used to simplify the basic dispersion model. The result, known as the Martin-Tikvart model, approximates plume spread in the crosswind direction and sums the contributions of all combinations of wind speeds and atmospheric stabiltities.

The concentration at any receptor point is obtained as the sum of the contributions from each point source of emissions. The accuracy of the concentration value for this type of model is dependent upon the proximity of the receptor point and the emission sources. Because the sources of emission are actually a collection of points, lines areas, and volumes, rather than merely a collection of points, as assumed in the model, greater accuracy generally results when the receptor point is not close proximity to any sources. To limit inaccuracies attributable to the point source, receptor locations within 100 meters of a point source were not considered in the results.

The model provided estimates of air pollutant concentrations both from aircraft alone and from all sources at a number of sites located in and around the selected airports. Receptors considered in this study were located according to the following overall scheme at air carrier airports: (1) one receptor at the center of each major terminal, (2) one receptor 100 meters from the head of each runaway, (3) sixteen receptors on the airport boundary, spaced equally on a compass rose located at the designated center of the airport, and (4) sixteen more receptors located in the airport surroundings, 5 kilometers from the center of the airport and spaced equally on the compass rose. Not more than 50 receptors were used, the actual number depending on the number of terminals and runways at each airport.

The resulting concentrations at the various receptor points were used in constructing isopleths of pollutant concentration. Isopleths were constructed for 6-9 a.m. hydrocarbon and annual NOx concentrations due to aircraft alone, and for aircraft contributions to total CO concentrations.

The model input data used in calculating annual concentrations of NOx were based on yearly distributions of wind direction, stability class and wind speed class, and annual average values of mixing height and emission rates. The short-term meteorological and activity conditions used to calculate the 8-hour and 1-hour CO conditions and the 6-9 a.m. hydrocarbon concentration were chosen to be representative of conditions that would be expected to yield high concentrations of these pollutants, i.e., low wind speed, high atmospheric stability, and low mixing height, and moderate to high aircraft activity. The conditions for calculation of short-term concentrations are presented in Table B-1.

Because the results of the model have not been extensively validated or verified, the concentrations generated by the model should be considered to be very approximate. They are useful, however, in indicating general pollutant concentration levels of the extent of aircraft contributions to localized pollutant concentration.

TABLE B-1

SHORT-TERM METEOROLOGICAL AND ACTIVITY CONDITIONS

	6-9 A.M. HC at L.A. Airport	8-Hour CO at L.A. Airport[a]	1-Hour CO LAX	ORD	JFK	DCA
Wind speed class	1	1	1	1	1	1
Stability class (Turner)	C	E	E	F	E	E
Wind direction, deg.	255	255	90	215	200	320
Wind variability, deg.	20	20	40	30	10	20
Mixing height, m.	200	200	535	700	960	980
Aircraft activity, LTO cycles.	60 (1970) 79 (1980)	260	54	49	30	34
Direction of movement	West	West	E	SW	S	N
Idle time at runway, sec.	60	150	240	260	540	300
Estimated annual frequency of occurrence of meteorological conitions	at least once		81	29[b]	10	67

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[a] These conditions are used in estimating ratios between aircraft generated and total 8-hour CO concentrations; the ratios are not sensitive to the conditions assumed.

[b] Based on 5 months of data.

APPENDIX C:

AREA -- SOURCE DISPERSION MODELING TO ESTIMATE DOWNWIND POLLUTANT CONCENTRATIONS

The modeling method used in this analysis involved approximating emissions both at airports and in surrounding areas as area sources, and relating these emissions to downwind pollutant concentrations by assuming Gaussian pollutant distribution in the vertical and crosswind directions. For each receptor point, the concentration caused by small-area elements was determined by integrating in the crosswind and upwind directions over each source region. The airport and surroundings were considered as separate source regions. The concentrations due to these two source regions were calculated separately then added together to obtain the total concentration at each receptor. Near the airport source, concentrations are the same as those from an area source of infinite extent.[32] At greater distances, edge effects caused by the finite width of the airport are considered by including the integration in the cross-wind direction. Also included is the limit to vertical mixing imposed by a more stable layer aloft.

For the purpose of this modeling, the airport was assumed to cover an area of 3.2 by 3.2 kilometers. The time period for the analysis, 8 a.m. to 11 a.m., was selected on the basis of recurring meteorological conditions conducive to high air pollutant concentrations. A diurnal correction factor was applied to the resulting concentrations to correct for the disproportionately greater amount of activity that occurred during this 3-hour period than occurred during other 3-hour periods during the day. The specific meteorological conditions used for the time period considered were: wind from west; stability class = 3, wind speed = 1.5 m/second mixing height = 200 m. These conditions are representative of severe conditions, from an air pollution standpoint, that are expected to occur at least once a year in the Los Angeles area.

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REFERENCES

1. Nature and Control of Aircraft Engine Exhaust Emissions. Report of the Secretary of Health, Education, and Welfare to the United States Congress. December 1968.

2. Jet Aircraft Emissions and Air Quality in the Vicinity of the Los Angeles International Airport. Air Pollution Control District, County of Los Angeles, California. April 1971.

3. The Potential Impact of Aircraft Emissions Upon Air Quality. Northern Research and Engineering Corporation. Final Report to the U. S. Environmental Protection Agency. Research Triangle Park, North Carolina. Contract Number 68-02-0085. December 1971.

4. Assessment of Aircraft Emission Control Technology. Northern Research and Engineering Corporation. Final Report to the U. S. Environmental Protection Agency. Research Triangle Park, North Carolina. Contract Number 68-04-0011. September 1971.

5. Analysis of Aircraft Exhaust Emission Measurements. Cornell Aeronautical Laboratory. Available from NTIS--PB 204-879. Contract Number 68-04-0040. October 1971.

6. National Primary and Secondary Ambient Air Quality Standards. Environmental Protection Agency. Federal Register 36(84):8187, April 30, 1971.

7. Air Quality Criteria for Hydrocarbons. U. S. DHEW, PHS, EHS, National Air Pollution Control Administration. Publication Number AP-64. Washington, D. C. March 1970.

8. Federal Air Quality Control Regions. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, North Carolina. Publication Number AP-102. January 1972.

9. Requirements for Preparation, Adoption, and Submittal of Implementation Plans. Environmental Protection Agency. Federal Register 36(158):15486, August 14, 1971.

10. Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, North Carolina. Publication Number AP-101. January 1972.

11. Climatography of U. S., Summary of Observations for Los Angeles International Airport, 1951-1960. U. S. Department of Commerce, Weather Bureau. Washington, D. C. 1962.

12. The State of California Implementation Plan for Achieving and Maintaining the National Ambient Air Quality Standards. California Air Resources Board. Sacramento, California. January 1972.

13. A Mathematical Model for Relating Air Quality Measurements to Air Quality Standards. Environmental Protection Agency, Office of Air Programs, Research Triangle Park, North Carolina. Publication Number AP-89. November 1971.

14. Nature and Control of Aircraft Engine Exhaust Emissions. Northern Research and Engineering Corporation. Final Report to the National Air Pollution Control Administration. Durham, North Carolina. Contract Number CPA 222-68-27. November 1968.

15. A Study of Aircraft Gas Turbine Engine Exhaust Emissions. Aerospace Industries Association. Washington, D. C. August 1971.

16. Collection and Assessment of Aircraft Emissions Baseline Data - Turbo-prop Engines. Detroit Diesel Allison Division (GMC). Available from NTIS--PB 202-961. Contract Number 68-04-0029. September 1971.

17. Exhaust Emissions Test: AiResearch Aircraft Propulsion and Auxiliary Power Gas Turbine Engines. AiResearch Division Garrett Corporation. Available from NTIS--PB 204-920. Contract Number 68-04-0022. September 1971.

18. Assessment of Aircraft Emission Control Technology. Northern Research and Engineering Corporation. Available from NTIS--PB 204-878. Contract Number 68-04-0011. September 1971.

19. Collection and Assessment of Aircraft Emissions - Piston Engines. Teledyne Continental Motors. Available from NTIS--PB 204-196. Contract Number 68-04-0035. October 1971.

20. Analysis of Aircraft Exhaust Emission Measurements: Statistics. Cornell Aeronautical Laboratory. Available from NTIS--PB 204-869. Contract Number 68-04-0040. November 1971.

21. A Study of Aircraft Powerplant Emissions (Piston and Turbine). Scott Research Laboratories, Inc. Available from NTIS--PB 207-107. Contract Number 68-04-0037. January 1971.

22. Collection and Assessment of Aircraft Emissions Baseline Data - Turbine Engines. Pratt and Whitney Aircraft. Available from NTIS--PB 207-321. Contract Number 68-04-0027. February 1972.

23. A Field Survey of Emissions from Aircraft Turbine Engines. U. S. Bureau of Mines, RI 7634. Bartlesville Energy Research Center, Bartlesville, Oklahoma.

24. Gaseous Emissions from a Limited Sample of Military and Commercial Aircraft Turbine Engines. Southwest Research Institute. Available from NTIS--PB 204-177. Interim Report, Contract Number EHS 70-108.

25. A Study of Exhaust Emissions from Reciprocating Aircraft Power Plants. Scott Research Laboratories. Available from NTIS--PB 197-627. Contract Number CPA 22-69-129. December 1970.

26. Design Criteria for Control of Nitrogen Oxide Emissions from Aircraft Turbine Engines. Ronald S. Fletcher, Richard D. Siegel, and E. Karl Bastress. Northern Research and Engineering Corporation. Report Number 1162-1.

27. Time Requirements for Retrofitting Jet Aircraft with Improved Combustor Design. Northern Research and Engineering Corporation. Final Report to National Air Pollution Control Administration, Durham, North Carolina. Contract Number CPA 22-69-90. July 1969.

28. Reduction of Nitrogen Oxides from Gas Turbines by Steam Injection. N. R. Dibelius, M. B. Hilt, and R. H. Johnson. ASME Paper 71-67-58, American Society of Mechanical Engineers.

29. A Study of Exhaust Emissions from Reciprocating Aircraft Power Plants. Scott Research Laboratories, Inc. Scott Project Number 1136. Final Report to the U. S. Environmental Protection Agency. Research Triangle Park, North Carolina. Contract Number CPA 22-69-129. December 1970.

30. Profile of Air Pollution Control. County of Los Angeles, Air Pollution Control District. 1971.

31. Ambient Carbon Monoxide Exposures. R. I. Larsen and H. W. Burke. APCA 69-167, Air Pollution Control Association. June 1969.

32. A Simple Method of Calculating Dispersion for Urban Areas. Steven R. Hanna. Journal of the Air Pollution Control Association, 21(12):774-777. December 1971.